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A DATA PACKAGE FOR THE VALIDATION OF A COMPUTER MODEL OF THE CCRL TUNNEL FURNACE FACILITY

P.M.J. HUGHES

CANMET
Canada Centre for Mineral and Energy Technology
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P.M.J. HUGHES

Combustion and Carbonization Research Laboratory

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A DATA PACKAGE FOR THE VALIDATION OF A COMPUTER MODEL OF THE CCRL TUNNEL FURNACE FACILITY

P.M.J. Hughes

Abstract

This report describes the results of a variety of experiments undertaken in the CANMET/Combustion and Carbonization Research Laboratory (CCRL) tunnel furnace facility for the generation of a data package. This data package is to be used for the validation of sophisticated computer codes that are capable of predicting the conditions inside the furnace during combustion. The report describes several experiments in the tunnel furnace in which low- and high-volatile coals were burned at two swirl settings and compared to oil. Also described are the measurement techniques and the reliability of the data. The data presented in this report make it possible to compare measured and predicted values for most of the information available from currently used computer codes.

COMPILATION D'UN ENSEMBLE DE DONNÉES POUR LA CERTIFICATION D'UN MODÈLE AUTOMATISÉ DU FOUR-TUNNEL DU LRCC

P.M.J. Hughes

Résumé

Les résultats de nombreuses expériences effectuées au moyen du four-tunnel du Laboratoire de recherche sur la combustion et la carbonisation de CANMET (LRCC) dans le but d'obtenir un ensemble de données sont présentés dans ce rapport. Cet ensemble de données sera utilisé pour la validation de codes machine spéciaux capables de prédire les conditions qui prévalent à l'intérieur du four tunnel pendant la combustion. L'auteur décrit plusieurs expériences portant sur la combustion à deux courants tourbillonnaires de charbon peu volatils et très volatils en établissant une comparaison avec la combustion de l'huile. Le rapport fait également état de techniques de mesure et de la fiabilité des données. Grâce aux données présentées dans ce rapport, il est possible, à partir de l'information obtenue des codes machine généralement utilisés, de comparer les valeurs mesurées aux valeurs prévues.

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INTRODUCTION

Combustion scientists have at their disposal two ways to study the combustion characteristics of a particular fuel. They can burn the fuel in an appropriate combustion system and measure the quantities they are interested in, or they can calculate them. The first alternative restricts the combustion scientist's knowledge of the fuel to the operating conditions and to the burning configuration used in the experiments. If the information of interest is limited in quantity and of a general nature, then the experimental method is generally preferred. However, as the amount of information required and the number of independent variables increase, so too does the cost of the experimental enquiry.

The alternative to the experimental technique is to model the combustion processes by a computer program. The level of sophistication of the computation routines can vary from calculating the global input-output relationship for a combustion process to determining the temperature and concentration fields in the combustor itself. The computer-modelling techniques are less time consuming and less costly in the long run when compared to the experimental methods. As a result, the test matrix used in computer-modelling programs can be much larger than that used in experimental programs. One drawback with modelling techniques is that the output of the program is only as good as the computer program itself. Thus, there is a strong requirement to ensure that the model gives a true representation of the processes occurring in the test device.

The simulation programs are made up of several sub-models that describe the individual physical processes occurring inside the combustion field. As the understanding of these processes improves, so too can the accuracy of the output of the programs. Experimentation has proven to be a useful tool to help in gaining a better understanding of these processes. As a result, a symbiotic relationship has developed between the computer-modelling and experimental investigative techniques, both of which enable a better understanding of actual combustion systems. The experimental methods have provided empirical parameters for the sub-models and a means for validation of the computer programs. The computer programs have in return provided insight into the processes occurring in the combustion field. In addition, the computer models have been used in combination with experimentation in a large matrix of tests. Consequently, the test series has been less costly and time consuming than if experimentation alone were used. Furthermore, the computer-modelling techniques can provide some missing information in a hybrid experimental/computer model test series.

A computer model has been developed for the prediction of the conditions inside the Combustion and Carbonization Research Laboratory (CCRL) tunnel furnace facility during the combustion of coal. A schematic of the furnace is shown in Figure 1. This furnace has been used for the determination of some of the empirical parameters used in the computer model and for the validation of the computer output. A complete description of the design of the furnace has been given previously (1).

The original computer model is capable of calculating the temperature and velocity fields in the gas and particulate streams, as well as the effect of the combustion on the oxygen concentration and heat transfer in the flame, which has been described previously (2). Considering the deficiencies of the data used for the validation and sub-model development, the model has resulted in rather good agreement with the measurements available (2).

The data used to validate the computer model of this furnace were taken from previous experiments that had not been specifically made for model validation. As a result, there were serious deficiencies in the data that led to difficulties in validation. These deficiencies involved the type and location of the measurements taken in the tunnel furnace. Coupled with these drawbacks were the lack of entrance velocity profiles and of the parameters used in the devolatilization and combustion models for the coals used. Consequently, a series of experiments were designed to address these deficiencies and to produce a data package that would provide the maximum of relevant information to the modeller. This report discusses the design and results from the experiments that produced this data package.

THE CCRL TUNNEL FURNACE

Figure 2 is a schematic of the interior of the furnace under investigation. The combustion chamber is approximately 5.0 m long and 1.0 m in diameter. The initial 0.75 m of the furnace is lined with a refractory to allow for radiative exchange to the fuel on entering the furnace, which enhances the devolatilization of the fuel. The remaining 4.22 m of the furnace length is surrounded by a cooled wall that simulates a thermal load. The cooled portion of the furnace is divided axially into 28 individually cooled sections each in the form of a 'C' (Fig. 1). Each 'C' section is monitored for temperature rise and flowrate, and thus measures the heat transfer to the wall at that particular axial location. The open portion of all the 'C' sections forms an axial slot down the length of the furnace that allows for the insertion of probes for flame measurement.

The furnace was designed to burn both solid and liquid fuels with a maximum thermal input of 0.6 MW. Any burner configuration can be used on this furnace; however, the burner used in these studies has a moving block type of swirl generator designed by the International Flame Research Foundation (IFRF) (3). A schematic of the interior of the furnace, including the burner quarl and refractory-lined section, is shown in Figure 2. As the swirl is adjusted, the flow or air in the swirled annulus is not obstructed, only the magnitude of the tangential component being changed. Thus only the swirl number is changed, the primary to secondary air ratio being maintained constant. The primary air and pulverized coal are carried to the furnace through the central 9.53 cm diameter pipe. For the tests discussed in this report, the primary air was not swirled. Various bluff bodies were used in some of the combustion experiments to improve the combustion of the low-volatility fuels. An illustration of the furnace that shows the geometry of the bluff bodies is given in Figure 3a and 3b.

DESCRIPTION OF THE EXPERIMENTAL PROGRAM

As noted earlier, the data packages prepared previously were from experiments not designed for computer model validation. As a result, there were data omitted that would have been useful to the modeller. Such information as the velocity profiles at the entrance to the furnace, heat flux measurements in the flame region, and the devolatilization and combustion model parameters of the fuel used are all very important for the successful prediction of the flow fields and combustion phenomena in the furnace. Also, in order to test the model properly it is useful to vary certain parameters by large amounts to study the effect on the output. Therefore, a series of experiments were designed to burn coals of radically different volatility at low and high swirl number in the tunnel furnace facility that would give a set of extreme conditions useful to the modeller.

The following is a list of the requirements of this experimental series:

1. The probes used in the experimental trials were recalibrated and the specific heat of the coolant used in the cooling rings of the furnace was redetermined.
2. The velocity profiles were measured at the entrance to, and at several axial locations inside, the furnace for various air flowrates and swirl settings.
3. A series of experiments were carried out using a well-characterized fuel oil in which the measurement techniques could be evaluated.
4. A previously studied high-volatile coal was burned as a reference for the low-volatile coal combustion studies. Low and high swirl numbers were used in both of these trials.
5. Regular calibration checks were instituted for the probes used in the furnace.
6. Standardized procedures were established for the combustion of the test fuel. These procedures included an equilibrating period of several hours after changing any operating parameter of the furnace.

The measurements and spatial distribution in the furnace, and the probes used to take them, are listed in Table 1. Figures 4-8 (indicated in Table 1), are schematics of the various probes used to take the measurements in the tunnel furnace.

Table 1 - Measurements

Measurement	Probe or technique used	Figure No.	Location of measurement	Comments
Gas velocity	5 hole pitot	4	Axial and radial at - Swirl gen exit - Cone exit - Refractory	 Cold flow Vary swirl Vary air flow
Radial heat transfer	Temp rise in 28 C circuits	1	After refractory at 28 axial locations on 15 cm centres	Average measurement
Radiative heat transfer	2 PI radiometer	5	Various axial locations including refractory zone	Calibration check
Total heat flux	Total heat flux meter	6	Various axial locations including refractory zone	Errors due to measurement technique (Appendix 3)
Gas concentration	Cooled probe continuous analyzers	7	Various axial and radial locations after refractory zone	Non iso-kinetic
Gas temperature	Water-cooled suction pyrometer	8	Various axial and radial locations after refractory zone	Errors due to measurement technique (Appendix 3)

VELOCITY PROFILE MEASUREMENTS

The initial conditions of the material entering the calculation domain are a major requirement for the correct prediction of phenomena inside the furnace during coal combustion. One of the most important measured variables is the variation of the velocity vector of the gases at the entrance to the furnace. This information is then used as an input boundary condition for the calculation procedures.

The spatial distribution of velocities inside the furnace can be used to validate the turbulent flow subroutines in the computer model.This is achieved by ignoring combustion in the computer model and making a comparison between the converged velocity field and the measurements taken in the furnace.

As indicated in Table 1, a five-hole pitot probe was used to measure the velocity vector of the gases in the furnace. The conditions for these measurements are shown in Table 2. The burner geometry (Fig. 2 without the bluff bodies) was used for the velocity profile measurements. It should be noted that the velocity measurements were made in the tunnel portion of the furnace at the higher air flowrate only, since those at the lower air flowrate were below the measurable threshold of the pitot probe. In all of the measurements, the ratio of primary to secondary air was maintained at 0.370. Measurements were taken on either side of the axis of symmetry to determine the flow asymmetry under the various experimental conditions. The swirl setting

Table 2 - Velocity profile measurements and locations

Axial location (m)	Measurement sites	Swirl settings	Air flowrates primary, secondary (kg/s)
exit swirl generator (0.0)	27 radial at 3 mm centres	0,0.5,1.0,2.0 3.0,4.0,4.5	0.0457,0.1235 0.2055,0.5557
exit of quarl (0.38)	40 radial at 5 mm centres	0,0.5,1.0,2.0 3.0,4.0,4.5	0.0457,0.1235 0.2055,0.5557
Tunnel 1st port (0.79)	22 radial at 20 mm centres	0,0.5,1.0,2.0 3.0,4.0,4.5	0.2055,0.5557
Tunnel 2nd port (1.07)	22 radial at 20 mm centres	0,0.5,1.0,2.0 3.0,4.0,4.5	0.2055,0.5557
Tunnel 3rd port (1.37)	22 radial at 20 mm centres	0,0.5,1.0,2.0 3.0,4.0,4.5	0.2055,0.5557

is only relative and does not correspond to the flow swirl number. The settings indicate the relative amount of secondary air for a tangential component of velocity. A more detailed description of the velocity profile measurement experiments is given in Reference 4.

It should be noted that the air flowrates used in the velocity profile measurements do not correspond to those used during the combustion trials. Appendix 1 discusses the necessary calculations to determine the entrance velocities for the various burner geometries and air flowrates used for the combustion experiments. Also given in Appendix 1 are the velocity profiles. These show the measured velocity data normalized by a reference velocity. As noted in the Appendix, the similarity of the velocity profiles indicates that the velocity components are not affected by a change in air flowrate. This becomes important when the profiles are applied to the combustion experiments since the primary to secondary air flow ratio was varied from one combustion trial to another.

THE COMBUSTION EXPERIMENTS

These experiments were run with three burner geometries shown in Figures 2, 3a and 3b. The physical and chemical characteristics of the fuels used and the operating conditions are given in Appendix 2. The measurements are discussed and results are categorized according to the burner geometry used. The combustion trials are given an alphabetic code and the coals a numerical code for identification purposes. Table 3 gives the experimental conditions corresponding to the alphabetic code describing the test.

Each of the combustion trials were conducted in the same manner. The furnace was preheated for 2 h with No. 2 fuel oil. The temperature at two depths within the refractory in the quarl section of the furnace was monitored. When these temperatures were found to remain relatively constant, it was decided that the furnace had come to an equilibrated condition and the feed fuel was changed over to the fuel of the day. The fuel feed rate and excess air and gas temperature at the furnace exit were monitored over a 2 h period to ensure that the furnace came to an equilibrated condition. At the end of this period a complete series of measurements were taken in the furnace. All

Table 3 - Combustion test conditions

Combustion trial	Burner geometry	Fuel, volatility (wt %)	Swirl setting	Excess oxygen (%)
A	Fig. 2	Oil, n.a.	0.0	5.0
B	Fig. 2	Oil, n.a.	3.0	5.0
C	Fig. 2	Coal, 34.59	0.0	5.0
D	Fig. 2	Coal, 34.59	3.0	5.0
E	Fig. 2	Coal, 34.59	1.0	5.0
F	Fig. 3a	Coal, 21.32	3.0	8.0
G	Fig. 3a	Coal, 21.32	4.5	8.0
H	Fig. 3b	Coal, 34.59	3.0	8.0
I	Fig. 3b	Coal, 34.59	4.5	8.0
J	Fig. 3b	Coal, 24.18	3.0	3.0
K	Fig. 3b	Coal, 24.18	4.5	3.0

of the measurements shown in Table 1, except velocity, were taken in the furnace while burning the chosen fuel at the chosen swirl setting. These measurements take about 4 h to complete and, as such, each experiment ran a full day. The results of all of the experiments are contained in Appendix 4.

An attempt was made to maintain the same geometry for each of the fuels burned in the furnace; however, because of the wide range of volatile content of the fuels used in this study, minor changes to the burner entrance geometry had to be made. These changes consisted of different conical bluff bodies (Fig. 3a and 3b) that served the purpose of enhancing the central recirculation zone and deflecting the coal into the swirling secondary air. Both of these effects improved the combustion characteristics of the lower volatile content coals. The necessary calculations to determine the entrance velocities for the combustion trials involving both bluff bodies are discussed in Appendix 1.

Before any comparisons are made between the combustion trials, it is suggested that the report be read in its entirety along with the Appendices. This is because, although an attempt was made to maintain certain variables constant for all of the combustion trials, there may be subtle differences between the experiments. Thus, the effect of varying one parameter may be masked by the influence of some other parameter.

This is true, for example, for the total heat flux measurements made near the flame. Throughout the combustion trials a neutral or slightly positive draft was maintained to ensure that the concentration and temperature measurements would not be contaminated with room air. Initially the furnace draft was measured inside the furnace exit. Since an induced draft fan was used, this draft measurement was lower than the actual draft in the furnace. This higher pressure caused the hot combustion gases to flow out of the sample ports, enhancing convective heat flux to the total heat flux probe and resulting in erroneous measurements. To remedy this problem, the location of the draft measurement was moved to the last 'C' cooling circuit just before the furnace exit. In using this new measurement location to balance the draft in the furnace, the hot gases no longer exited the sampling port and therefore did not influence the total heat flux measurement as before. Because of this, if an attempt were made to compare the total heat flux measurements of the two combustion trials erroneous conclusions might be made.

In order to give the modeller an insight into the subtle differences between the individual combustion trials, Appendix 2 also includes a discussion of observations and minor changes to the experiments. This information should assist in the interpretation of the experimental results.

USE OF THE DATA PACKAGE

There are two steps recommended for the accurate modelling of conditions inside the furnace during the combustion of fuel. The first step involves the modelling of the flow fields inside the furnace without combustion in order to validate the turbulence and gas flow routines in the program. The second step is to model the conditions inside the furnace during combustion. For this, it is recommended to model the simplest burner geometry first. Since better results have been obtained with the high-volatile coal, combustion trials C, D or E should be modelled first. The following is an outline of the recommended procedure for the validation of a computer model for the prediction of the conditions inside a furnace during the combustion of the selected test fuels.

TURBULENCE AND FLOW-MODELLING VALIDATION

The data referred to in Appendix 1 can be used for the validation of the gas flow subroutines in combustion model programs. Once the solid boundaries of the furnace have been defined (Fig. 1 and 2), then a choice is made of the flow situation to model. This choice will depend on the situation to be studied during combustion. It is suggested that the swirl number of the noncombusting simulation be close to that to be modelled in the combusting situation. This is because the confidence that can be placed on the flow and turbulence subroutines during the combusting situation will have a direct bearing on the results of the cold flow validation. It should be noted that the swirl number be used and not the swirl setting as reported in various tables in this report. Furthermore, if a computer simulation will be run for the furnace as a whole, then the velocity profile experiments with the high flowrate should be used. If, however, it is wished to study the flow and turbulence subroutines in the near flame region, then the velocity profile experiment with either the low or high flowrate can be used.

Suppression of combustion in the field under study is handled in different ways in each combustion model, so this will not be discussed in this report.

COMBUSTION VALIDATION PROCEDURES

Once the cold flow validation has been successfully completed, then the validation of the combustion subroutines can occur. As stated above, trials C, D or E should be used first. The combustion (and noncombustion) trials with higher swirl settings tend to give more symmetric profiles than those at lower swirl settings. As a result, these higher swirl trials should be used first.

Once the combustion experiment has been chosen, the entrance conditions for the simulation must be determined. The entrance velocity profiles can be determined by referring to the appropriate section in Appendix 1 under "Implementation of Velocity Measurements". The effect of the bluff bodies is expected to vary depending on the body geometry used. The most accurate estimate of the entrance velocity profile will be for the experiments without the bluff body, i.e., for experiments A to E. As stated in Appendix 1, because of the geometry of the bluff body, experiments that use the bluff body of Fig. 3b

(H, I, J, and K) will have the least accurate estimation of the entrance velo- city profiles.

Appendix 2 can be used to determine the necessary input information concerning the fuel and running conditions. For combustion trials C, D and E there is no breakdown of the fine particle size -400 mesh. Estimations of this can be made from the breakdown for other combustion trials, since the settings on the coal pulverizer were not modified over a large range. Information concerning the nozzle used for the no. 2 oil combustion trials can be found in Appendix 2. Once the input information has been determined Appendix 4 can be used to compare the converged results with the measured data.

When making comparisons with measured data, it is important to note the possible variation in the measurements resulting from the limitations of the techniques used. Appendix 3 contains a brief discussion of the error analysis of the measurement techniques used to generate the data package.

CONCLUSIONS

A set of experiments has been designed and carried out to give data that can be used to validate coal or oil flame computer models. It is expected that the results of these experiments respond to the deficiencies of the data packages that had been previously prepared but not specifically generated for comparison with computer predictions. By following Appendices 1 and 2, it is possible to prepare input to the computer programs that predict conditions inside the furnace of Figure 2. With these predictions, a comparison can then be made to the actual measurements tabulated in Appendix 4.

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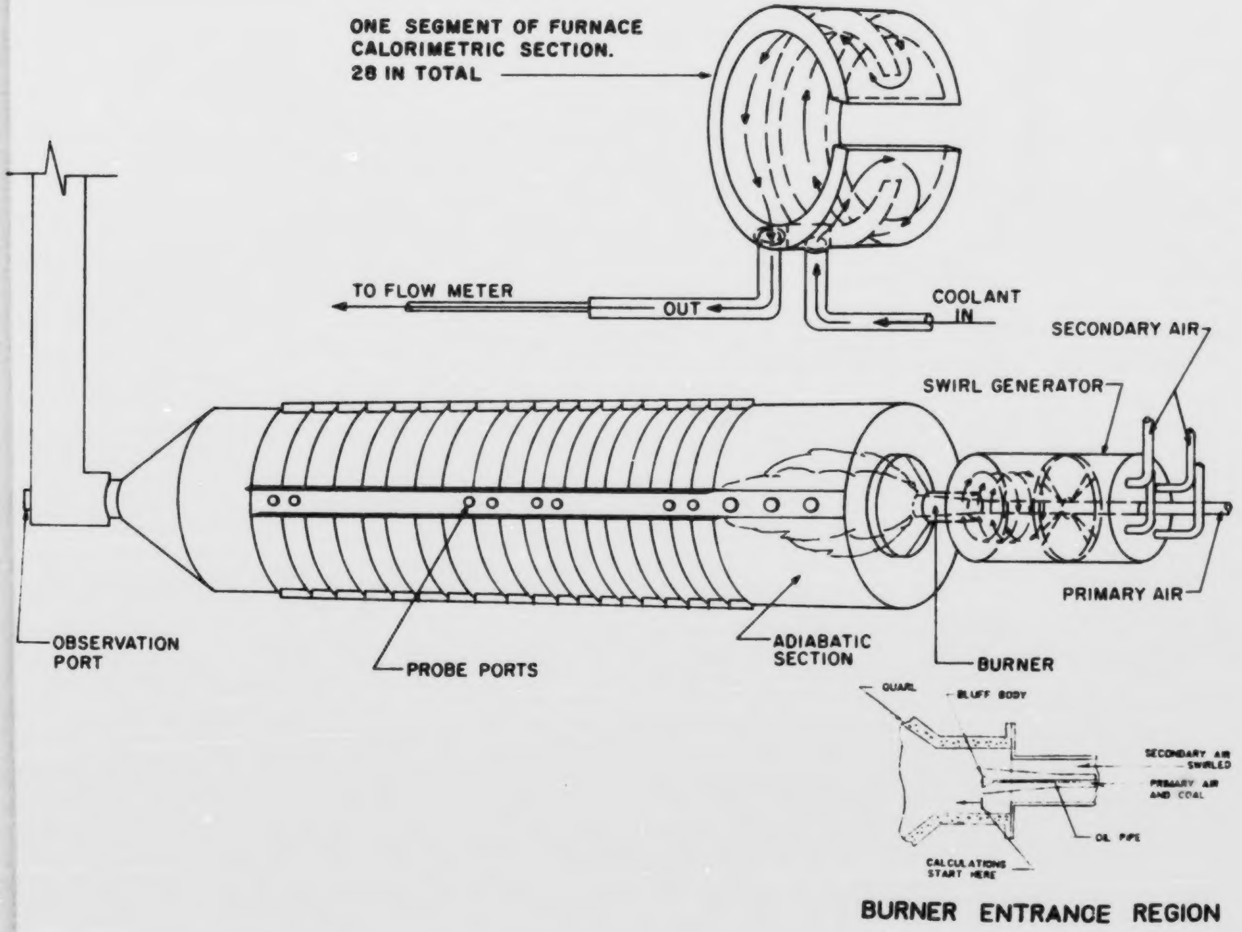

ONE SEGMENT OF FURNACE
CALORIMETRIC SECTION.
28 IN TOTAL
TO FLOW METER
OUT
COOLANT
IN
SECONDARY AIR
SWIRL GENERATOR
PRIMARY AIR
OBSERVATION
PORT
PROBE PORTS
ADIABATIC
SECTION
BURNER
QUARL
BLUFF BODY
SECONDARY AIR
SWIRLED
PRIMARY AIR
AND COAL
OIL PIPE
CALCULATIONS
START HERE
BURNER ENTRANCE REGION

Fig. 1 - Schematic of tunnel furnace showing the entrance region without bluff body

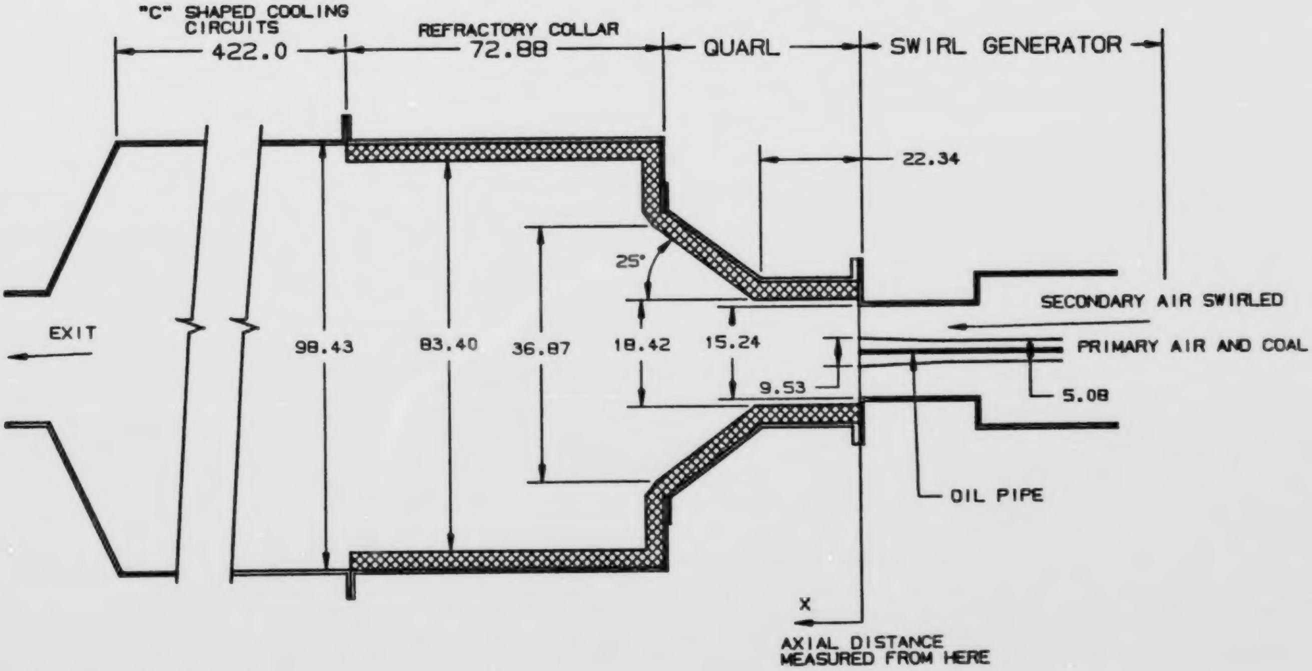
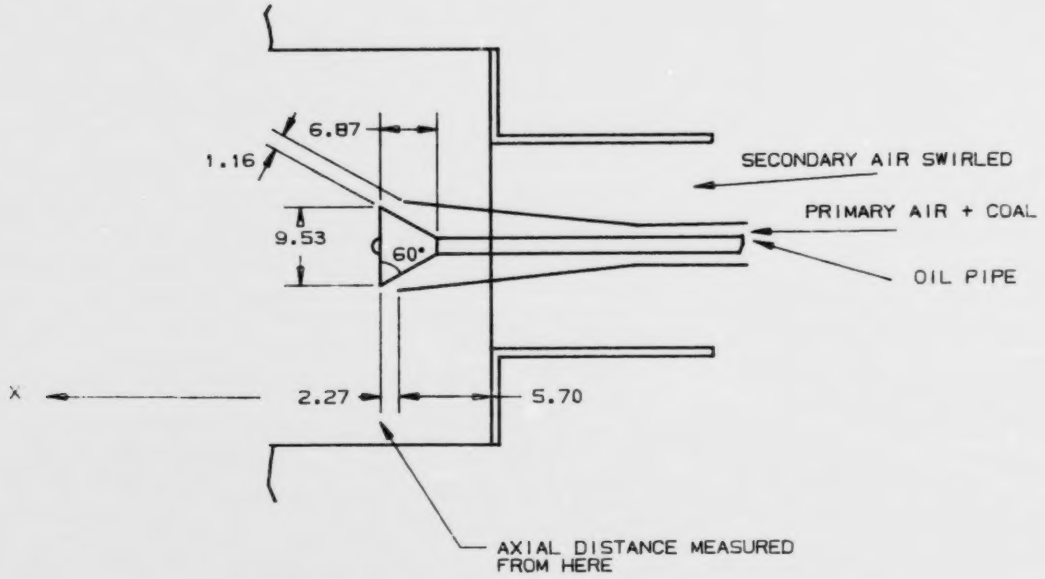
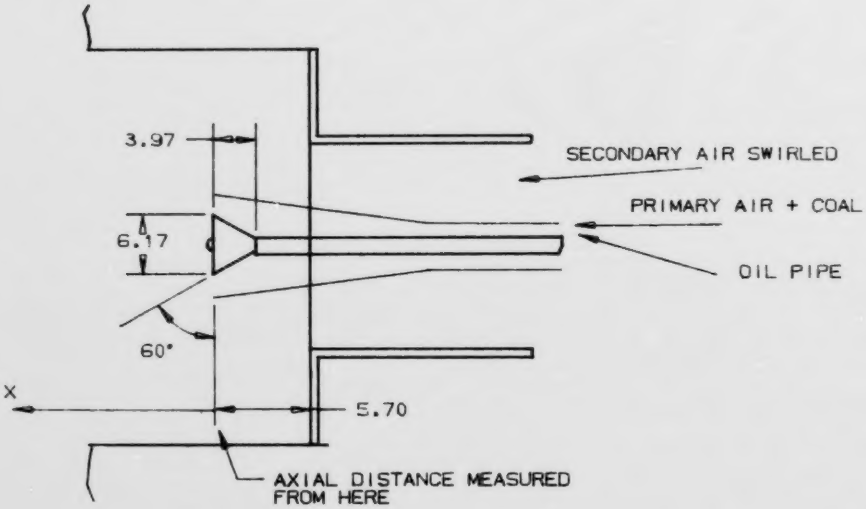

"C" SHAPED COOLING CIRCUITS
422.0
REFRACTORY COLLAR
72.88
QUARL
SWIRL GENERATOR
22.34
25°
SECONDARY AIR SWIRLED
EXIT
98.43
83.40
36.87
18.42
15.24
PRIMARY AIR AND COAL
9.53
5.08
OIL PIPE
X
AXIAL DISTANCE MEASURED FROM HERE

Fig. 2 - Schematic of the interior of the tunnel furnace


6.87
1.16
9.53
60°
SECONDARY AIR SWIRLED
PRIMARY AIR + COAL
OIL PIPE
X
2.27
5.70
AXIAL DISTANCE MEASURED FROM HERE

(a)


3.97
6.17
60°
SECONDARY AIR SWIRLED
PRIMARY AIR + COAL
OIL PIPE
X
5.70
AXIAL DISTANCE MEASURED FROM HERE

(b)

Fig. 3 - Schematic of the entrance region of the tunnel furnace with bluff bodies

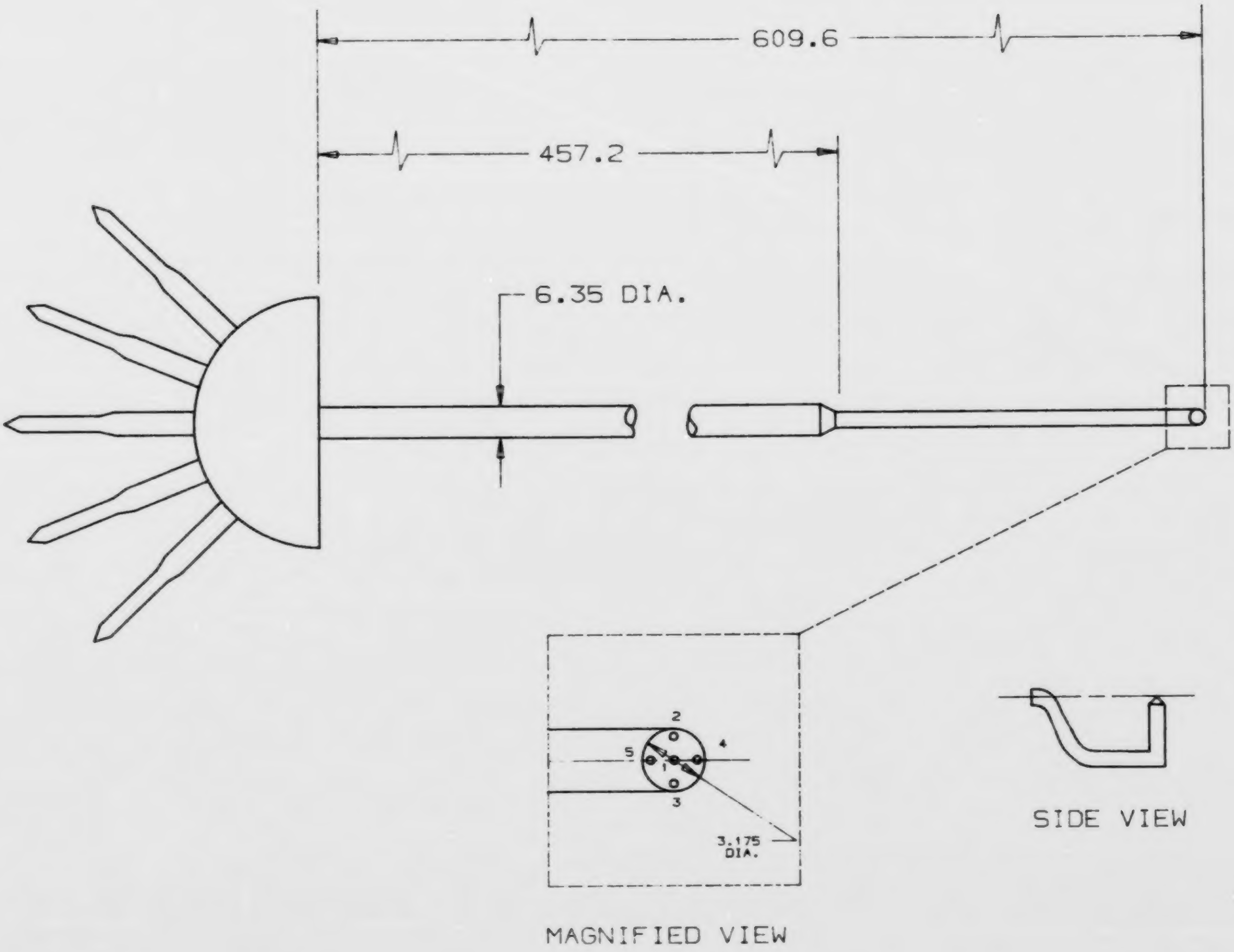

609.6
457.2
6.35 DIA.
2
5
4
1
3
3.175 DIA.
SIDE VIEW
MAGNIFIED VIEW

Fig. 4 - Schematic of the five-hole pitot probe used for the velocity profile measurement

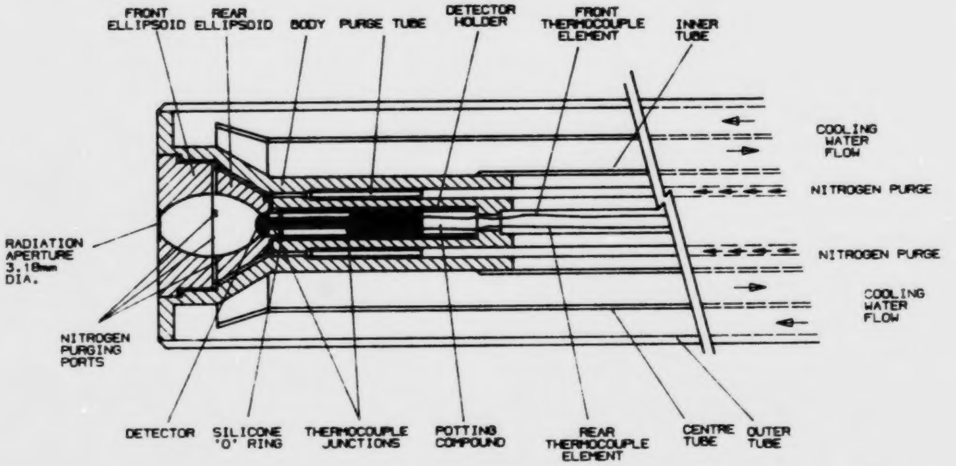

FRONT ELLIPSOID
REAR ELLIPSOID
BODY
PURGE TUBE
DETECTOR HOLDER
FRONT THERMOCOUPLE ELEMENT
INNER TUBE
COOLING WATER FLOW
NITROGEN PURGE
RADIATION APERTURE 3.18mm DIA.
NITROGEN PURGE
COOLING WATER FLOW
NITROGEN PURGING PORTS
DETECTOR
SILICONE 'O' RING
THERMOCOUPLE JUNCTIONS
POTTING COMPOUND
REAR THERMOCOUPLE ELEMENT
CENTRE TUBE
OUTER TUBE

Fig. 5 - Schematic of the 2 pi radiometer

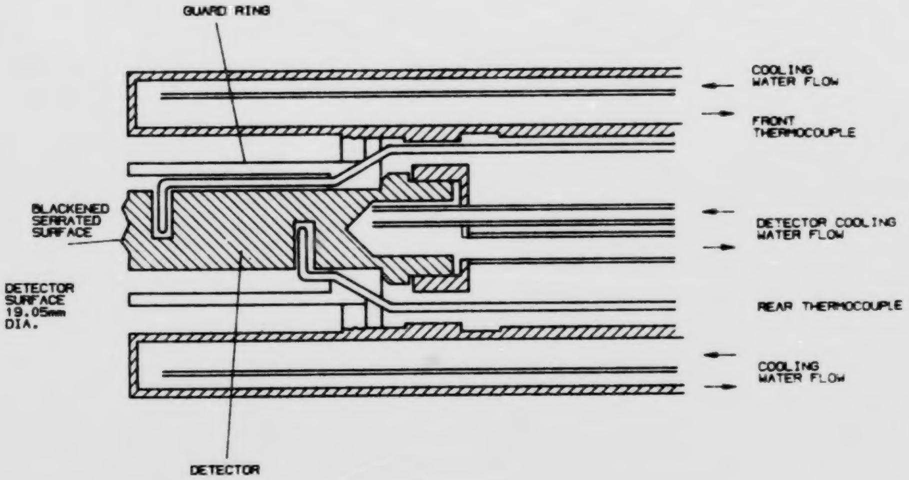

GUARD RING
COOLING WATER FLOW
FRONT THERMOCOUPLE
BLACKENED SERRATED SURFACE
DETECTOR COOLING WATER FLOW
DETECTOR SURFACE 19.05mm DIA.
REAR THERMOCOUPLE
COOLING WATER FLOW
DETECTOR

Fig. 6 - Schematic of the total heat flux meter

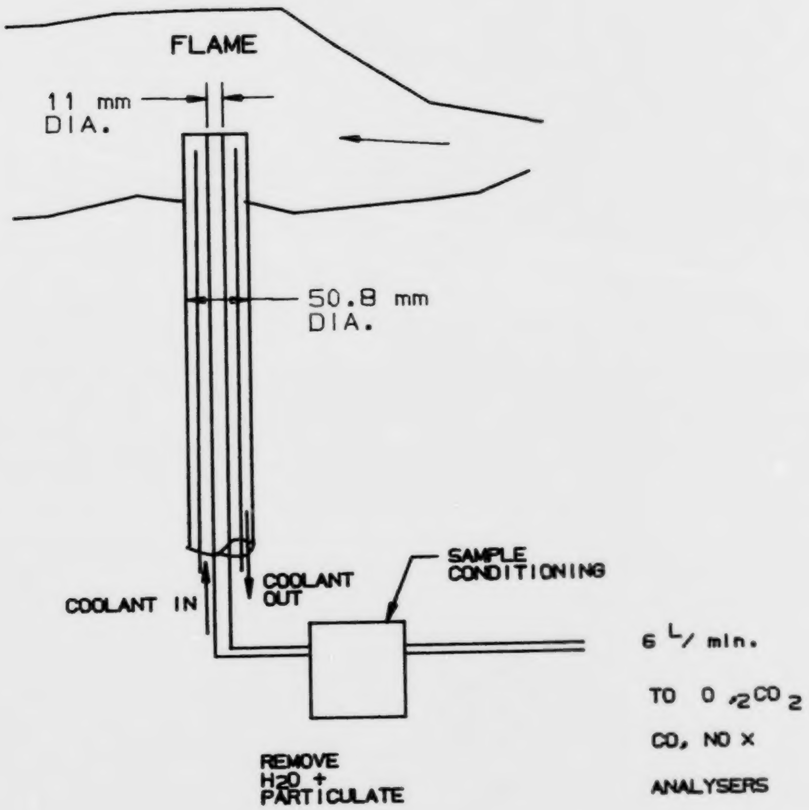

FLAME
11 mm DIA.
50.8 mm DIA.
SAMPLE CONDITIONING
COOLANT IN
COOLANT OUT
6 L/ min.
TO O2, CO2
CO, NO x
ANALYSERS
REMOVE H2O + PARTICULATE

Fig. 7 - Schematic of the gas sampling system

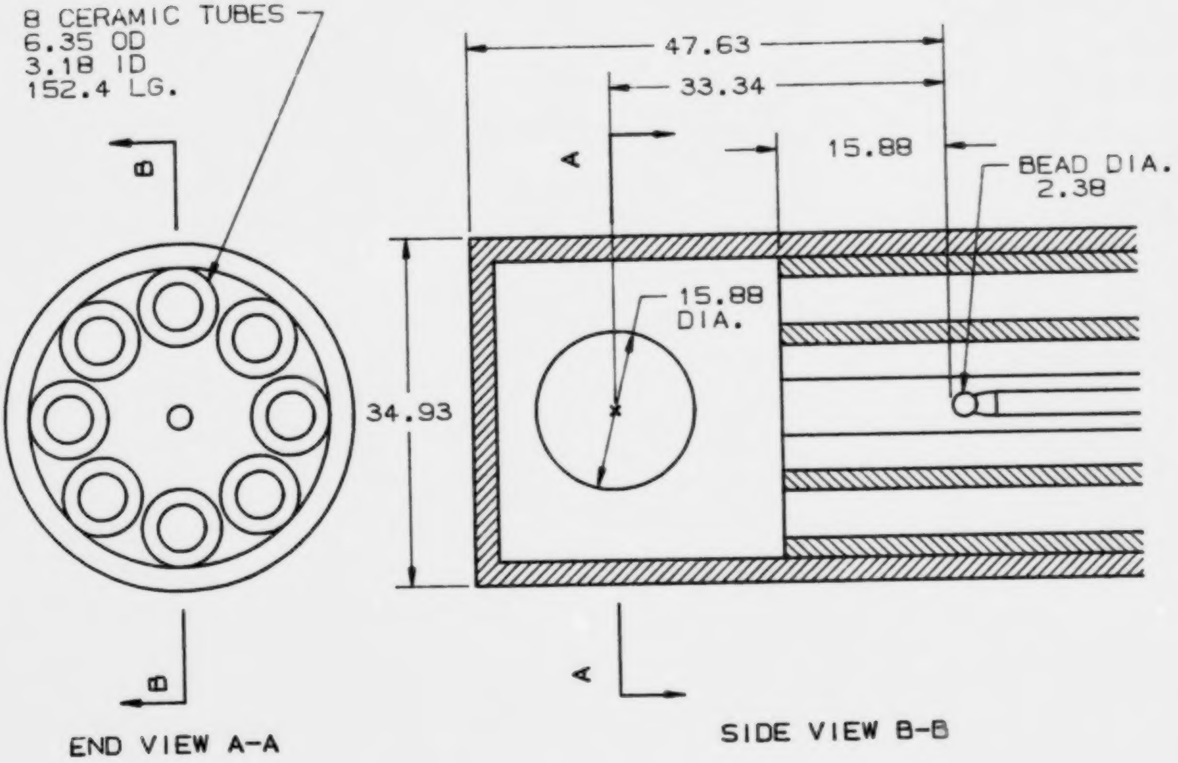

8 CERAMIC TUBES
6.35 OD
3.18 ID
152.4 LG.
B
B
END VIEW A-A
47.63
33.34
15.88
BEAD DIA.
2.38
A
A
15.88
DIA.
34.93
SIDE VIEW B-B

Fig. 8 - Schematic of the suction pyrometer

APPENDIX 1

VELOCITY PROFILE MEASUREMENTS

APPENDIX 1

VELOCITY PROFILE MEASUREMENTS

INTRODUCTION

In order to accurately model conditions inside the furnace during combustion, it is necessary to know the conditions at the entrance to the calculation domain. For this reason, a series of experiments were undertaken to measure the velocity of the gases flowing in the furnace. These experiments were made under isothermal conditions at ambient temperature because the velocity probe did not have a cooling jacket to protect it from the flame. A complete description of the conditions under which the measurements were taken and the data reduction methods are discussed in Reference 4.

It was thought that a complete mapping of the velocity field would be of greater use to the modeller than simply the velocity of the gases at the exit of the burner. The modeller can use the velocity measurements to make a comparison with his model output in the noncombusting situation and thereby verify the modelling of the aerodynamics and flow inside the furnace. As a result, velocity measurements were made at five axial locations, two total air flowrates, and seven swirl settings. The ratio of primary to secondary air was maintained at 0.37 for all of the velocity profile measurements. These measurements at the various axial locations involved the resolution of the gas velocity into its rectangular components. Axial symmetry was assumed; however, measurements were taken on both sides of the axis of symmetry to ensure this. The recirculation zones were also mapped out using the tuft technique.

EXPERIMENTAL RESULTS

Table 2 shows the experimental conditions used for the velocity profile measurements. Tables A1-1 to A1-46 list the velocity measurements at each of the axial locations for all of the flow conditions. These data are shown plotted in Figures A1-1 to A1-46. Encircled points are symmetry data points. In these tables and graphs there are some data missing. When the pitch angle calculated for the velocity vector is beyond the acceptance angle for the probe, the measurement is deemed invalid and is therefore rejected. Figures A1-47 to A1-52 show the recirculation zones as determined by the tuft technique. The shaded regions are the zones of reversed flow.

DISCUSSION OF RESULTS

The velocities plotted in Figures A1-1 to A1-46 are made dimensionless by a reference velocity. This reference velocity is determined by the mass flowrate and the flow area. The mass flowrate for the measurements at the swirl generator exit is calculated from the integral of the velocity profiles themselves. At all the other measurement stations, the mass flowrate is that determined from the flow measurement devices used to set the primary and secondary flowrates. The reference velocities used to non-dimensionalize the velocities are shown in Table A1-47.

A detailed discussion of the results of the velocity profile measurements is given in Reference 4.

IMPLEMENTATION OF VELOCITY MEASUREMENTS

These velocity profile measurements can be used to validate the computer programs that predict the flow in the tunnel furnace. There are two ways these data can be used. First, the complete mapping of the velocity field in the furnace can be used to verify the turbulent flow calculation routines. This is done by disallowing combustion in the computer model. By using the velocity measurements at the exit of the swirl generator as the entrance conditions for the calculation domain, the program is allowed to converge on a solution to the flow in the furnace. The calculated velocity field is then compared to that measured. The velocity measurements can also be used as an entrance boundary condition for the simulation of the flow during the combustion situation. The converged velocity field is then assumed to be the real velocity field based on the confidence demonstrated in the noncombustion situation.

To ensure the best chance of a successful comparison between the experimental and calculated situation inside the furnace, input to the computer program must be as realistic as possible. The velocity profile measurements are used as input to the simulation program; however, some modifications to these data must be made. These modifications result from the fact that the burner geometry and the flow situation for the velocity measurements were different from those during the combustion experiments. The following sections discuss the necessary calculations to modify the velocity profile measurements so that they closely resemble the air velocities at the entrance to the calculation domain. The effect of the bluff bodies on the velocity profiles is handled in separate sections.

COMBUSTION EXPERIMENTS WITHOUT BLUFF BODY (Fig. 2)

For the velocity profile measurements, it was impossible to simulate the air flow conditions for every conceivable combustion experiment. Therefore, it was decided that two total air flowrates would be used for the velocity profile experiments with the ratio of primary to secondary air flow maintained constant at 0.37. This was done to indicate the validity to the scale-up technique used for matching the air flow conditions of the velocity profile experiments to those of the combustion experiments.

By observing the various velocity profiles at the different axial locations, it is evident that the shape of the velocity profile does not change when the total air flowrate is increased (Fig. A1-1 to A1-46). These velocity profiles have been made non- dimensional by an average velocity and therefore they can be scaled up by an average flow velocity without causing a distortion in the shape of the velocity profile.

The following equation is used to scale-up the velocity profiles so that the entrance gas velocities more closely resemble those during the combustion experiments:

$$\hat{M}_E/\hat{M}_V = (\rho \text{ x } A \text{ x } V)_E/(\rho \text{ x } A \text{ x } V)_V \qquad \text{Eq 1}$$

where:

$\dot{M}$ = mass flowrate of air
ρ = air density
A = flow area
V = velocity.

and the subscripts:

E = the combustion expts
V = the velocity profile expts.

Using Eq 1 and the fact that the flow area is the same for both the combustion and velocity profile experiments, the following general equation results:

$$(V_{ij})_E = (\dot{M}_j)_E/(\dot{M}_j)_V \times [(\rho_j)_V/(\rho_j)_E] \times (V_{ij})_V \qquad \text{Eq 2}$$

where the subscripts:

i = the axial, radial or tangential components of the velocity
j = the primary or secondary air portions of the profile
E and V as above.

Equation 2 can be used for the primary or secondary air since the flow area is the same for both sets of experiments.

COMBUSTION EXPERIMENTS WITH THE LONG BLUFF BODY (Fig. 3a)

The combustion experiments using the long bluff body (Fig. 3a) require a two-step modification. The modifications include the effects of the different flow conditions during the combustion experiment and of the presence of the bluff body in the primary air flow. As can be seen in Fig. 3a, the bluff body changes not only the flow area and thus the air velocity but also changes the direction of the flow. As shown in the figure, the bluff body completely covers the primary air portion of the exit of the swirl generator. As such, the physical presence of the bluff body will cause the air velocity in the primary air region of the swirl generator exit to be zero, and will change the direction and magnitude of the air velocity vector in the secondary air annulus. For reasons of simplicity, the effect of directing the primary air into the secondary air region will be handled separately from the effect of the change in the flow conditions. The velocity profiles in the primary and secondary air portion of the swirl generator can be handled separately because they were fed by separate air supplies.

Equation 2 can be used to determine the effect of the change in flow conditions on the secondary air velocities. Therefore, as a result of simply changing the air flowrate of the secondary air, the individual components of velocity in the secondary air portion of the swirl generator exit can be expressed as:

$$(V_{is})_F = (\dot{M}_s)_E/(\dot{M}_s)_V \times [(\rho_s)_V/(\rho_s)_E] \times (V_{is})_V \qquad \text{Eq 3}$$

where the subscripts:

s = the secondary air portion of the profile
F = flowrate changes
E, i and V as above.

In order to include the effect of deflecting the primary air into the secondary air portion of the velocity profile, the average velocity of the air deflected is calculated from the following:

$$(V_p)_E = (\dot{M}_p)_E/[(\rho_p)_E \times (A_p)_E] \qquad \text{Eq 4}$$

The area $(A_p)_E$ is calculated by dropping a perpendicular to the bluff body surface from the end of the primary air pipe and determining the surface of revolution about the axis of the bluff body (Fig. 3a). Thus:

$$\begin{aligned}(A_p)_E &= \text{PI} \times (4.77+3.765) \times 1.16 \\ &= 31.104\ \text{cm}^2\end{aligned}$$

As the velocity $(V_p)_E$ is deflected into the secondary air flow region, only the radial and axial components of the secondary air velocity will be affected. It is assumed that there is no tangential component of primary air velocity. Thus, the radial component of the primary air deflected into the secondary air section is found as:

$$\begin{aligned}(V_{rp})_E &= (V_p)_E \times \cos(60)\\ &= [(\dot{M}_p)_E \times \cos(60)]/[(\rho_p)_E \times (A_p)_E] \qquad \text{Eq 5}\end{aligned}$$

and similarly the axial component is:

$$\begin{aligned}(V_{xp})_E &= (V_p)_E \times \sin(60)\\ &= [(\dot{M}_p)_E \times \sin(60)]/[(\rho_p)_E \times (A_p)_E] \qquad \text{Eq 6}\end{aligned}$$

Each of these values are added to the corresponding components in the secondary air portion of the flow leaving the swirl generator. Thus, the radial and axial components of velocity are found from the following equations:

$$\begin{aligned}(V_{rs})_E &= [(\dot{M}_p)_E \times \cos(60)]/[(\rho_p)_E \times (A_p)_E]\\ &\quad + [(\dot{M}_s)_E \times (\rho_s)_V]/[(\dot{M}_s)_V \times (\rho_s)_E] \times (V_r)_V \qquad \text{Eq 7}\end{aligned}$$

$$\begin{aligned}(V_{xs})_E &= [(\dot{M}_p)_E \times \sin(60)]/[(\rho_p)_E \times (A_p)_E]\\ &\quad + [(\dot{M}_s)_E \times (\rho_s)_V]/[(\dot{M}_s)_V \times (\rho_s)_E] \times (V_x)_V \qquad \text{Eq 8}\end{aligned}$$

Special care must be taken when applying the above equations to the velocity profile data. These equations are supplied in order to give the modeller an indication of the real situation concerning the velocity profiles at the entrance to the calculation domain. The velocity calculated in Eq 4 is an average quantity and must be treated as such. Furthermore, care must be taken in applying the above equations near solid boundaries.

COMBUSTION EXPERIMENTS WITH SHORT BUFF BODY (Fig. 3b)

It is expected that the determination of the effect of using the short bluff body on the velocity profiles will be the least accurate to predict. This is because only a portion of the primary air flow is deflected by the bluff body, as can be seen in Figure 3b. The resultant effect on the primary air velocity profile is difficult to determine. In the following analysis, the effects of the presence of the bluff body and the change in flow conditions will again be handled separately. Furthermore, the primary and secondary air portions of the flow will also be handled individually.

Equation 3 can be used to determine the velocity components of the air flowing in the secondary air portion of the flow purely as a result of the change in air flow from the velocity profile experiments.

The velocity components for the air flowing through the primary air portion of the swirl generator exit are somewhat more complicated to determine. Equation 1 is used to calculate the magnitude of the primary air velocity from the velocity profile measurements. Thus:

$$(V_p)_E = [(\dot{M}_p)_E/(\dot{M}_p)_V] \times [(\rho_p)_V \times (A_p)_V]/[(\rho_p)_E \times (A_p)_E] \times (V_p)_V \qquad \text{Eq 9}$$

where

$(A_p)_V$ = 71.331 CM2
$(A_p)_E$ = 41.412 CM2.

Because the flow is deflected by the bluff body before leaving the swirl generator exit, the velocity calculated above will be portioned out to the axial and radial directions. It is assumed that the shapes of the axial and radial profiles do not change from the velocity measurement experiments. Therefore, the axial and radial components of velocity for the flow in the primary air region of the swirl generator exit are as follows:

$$(V_{xp})_E = [(\dot{M}_p)_E/(\dot{M}_p)_V] \times \{[(\rho_p)_V \times (A_p)_V]/[(\rho_p]_E \times (A_p)_E]\} \times (V_{xp})_V \times \sin(60) \qquad \text{Eq 10}$$

$$(V_{r\rho})_E = [(\dot{M}_p)_E/(\dot{M}_p)_V] \times \{[(\rho_p)_V \times (A_p)_V]/[(\rho_p)_E \times (A_p)_E]\} \times (V_{rp})_V + (V_{xp})_V \times \cos(60) \qquad \text{Eq 11}$$

As stated above, care should be taken in applying Equations 10 and 11, particularly in the region near the flow boundaries. These computations may result in slightly distorted velocity profiles; however, the effect in the far field in the tunnel portion of the furnace is expected to be small. It is also believed that the resulting profiles will give a closer approximation to the real situation when compared to the conventional practice of assuming flat entrance velocity profiles.

Table A1-1 - Velocity profile data

Swirl setting - 0.0 high total air flow rate
Primary air temperature - 50.0°C
Secondary air temperature - 38.0°C
Axial location of traverse: exit swirl generator (x = 0.0 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	46.01	0.00	2.34	1.273	0.000	0.061
3.0	50.33	0.00	2.68	1.308	0.000	0.070
6.0	51.60	0.00	3.17	1.341	0.000	0.082
9.0	52.85	0.00	3.69	1.373	0.000	0.096
12.0	54.07	0.00	4.19	1.405	0.000	0.109
15.0	54.45	0.00	4.79	1.415	0.000	0.124
18.0	53.21	0.00	5.31	1.382	0.000	0.138
21.0	51.47	0.00	5.85	1.337	0.000	0.152
24.0	47.91	0.00	6.21	1.245	0.000	0.161
27.0	42.80	0.00	6.38	1.112	0.000	0.166
30.0	34.03	0.00	6.31	0.962	0.000	0.164
33.0	30.76	0.00	5.98	0.799	0.000	0.155
36.0	24.52	0.00	5.31	0.637	0.000	0.138
39.0	18.85	0.00	4.53	0.490	0.000	0.118
42.0	13.52	0.00	3.81	0.351	0.000	0.099
45.0	8.31	0.00	2.56	0.216	0.000	0.067
51.0	47.13	0.00	-1.36	1.225	0.000	-0.035
54.0	47.05	0.00	-0.19	1.222	0.000	-0.005
57.0	46.68	0.00	0.79	1.213	0.000	0.020
60.0	46.25	0.00	1.25	1.202	0.000	0.033
63.0	45.81	0.00	1.76	1.190	0.000	0.046
66.0	45.59	0.00	2.33	1.184	0.000	0.061
69.0	45.26	0.00	2.84	1.176	0.000	0.074
72.0	44.30	0.00	3.48	1.151	0.000	0.090
75.0	36.83	0.00	3.93	0.957	0.000	0.102
76.0	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-2 - Velocity profile data

Swirl setting - 0.0 low total air flow rate

Primary air temperature - 55.0°C

Secondary air temperature - 29.0°C

Axial location of traverse: exit swirl generator (x = 0.0 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	11.18	0.00	1.19	1.219	0.000	0.130
3.0	11.12	0.00	1.31	1.212	0.000	0.143
6.0	11.38	0.00	1.46	1.241	0.000	0.159
9.0	11.68	0.00	1.54	1.274	0.000	0.168
12.0	11.95	0.00	1.68	1.303	0.000	0.183
15.0	12.25	0.00	1.84	1.336	0.000	0.200
18.0	12.11	0.00	1.99	1.321	0.000	0.217
21.0	11.98	0.00	2.15	1.306	0.000	0.235
24.0	11.33	0.00	2.28	1.235	0.000	0.248
27.0	10.55	0.00	2.34	1.151	0.000	0.255
30.0	8.94	0.00	2.38	0.975	0.000	0.260
33.0	7.54	0.00	2.47	0.822	0.000	0.270
36.0	5.92	0.00	2.55	0.645	0.000	0.278
39.0	4.14	0.00	2.80	0.452	0.000	0.306
48.0	7.30	0.00	0.31	0.796	0.000	0.034
51.0	10.94	0.00	0.71	1.193	0.000	0.077
54.0	10.92	0.00	1.03	1.191	0.000	0.113
57.0	10.77	0.00	1.26	1.174	0.000	0.137
60.0	10.55	0.00	1.43	1.151	0.000	0.156
63.0	10.48	0.00	1.61	1.143	0.000	0.176
66.0	10.36	0.00	1.79	1.129	0.000	0.195
69.0	10.23	0.00	1.95	1.116	0.000	0.212
72.0	9.85	0.00	2.07	1.074	0.000	0.226
75.0	8.14	0.00	2.22	0.887	0.000	0.242
76.0	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-3 - Velocity profile data

Swirl setting - 0.5 high total air flow rate

Primary air temperature - 51.0°C

Secondary air temperature - 39.0°C

Axial location of traverse: exit swirl generator (x = 0.0 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	49.32	0.00	2.46	1.308	0.000	0.065
3.0	50.41	0.00	2.72	1.337	0.000	0.072
6.0	51.65	0.00	3.21	1.370	0.000	0.085
9.0	52.83	0.00	3.68	1.401	0.000	0.098
12.0	53.95	0.00	4.24	1.431	0.000	0.113
15.0	54.54	0.00	4.80	1.446	0.000	0.127
18.0	53.69	0.00	5.43	1.424	0.000	0.144
21.0	51.55	0.00	5.85	1.367	0.000	0.155
24.0	47.75	0.00	6.30	1.267	0.000	0.167
27.0	42.74	0.00	6.44	1.134	0.000	0.171
30.0	36.78	0.00	6.44	0.976	0.000	0.171
33.0	30.62	0.00	6.02	0.812	0.000	0.160
36.0	24.50	0.00	5.42	0.650	0.000	0.144
39.0	18.41	0.00	5.31	0.488	0.000	0.141
42.0	13.39	0.00	3.93	0.355	0.000	0.104
45.0	8.56	0.00	2.07	0.227	0.000	0.055
48.0	14.32	0.75	-9.05	0.380	0.020	-0.240
51.0	46.96	1.23	-1.41	1.246	0.033	-0.037
54.0	47.29	2.89	0.11	1.254	0.077	0.003
57.0	46.64	4.49	0.89	1.237	0.119	0.024
60.0	45.83	6.85	1.52	1.215	0.182	0.040
63.0	45.49	7.61	1.98	1.206	0.202	0.052
66.0	45.05	8.76	2.45	1.195	0.232	0.065
69.0	44.79	9.93	3.00	1.188	0.263	0.079
72.0	43.59	10.87	3.60	1.156	0.288	0.096
75.0	39.24	9.78	4.14	1.041	0.259	0.110
76.0	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-4 - Velocity profile data

Swirl setting - 0.5 low total air flow rate
Primary air temperature - 60.0°C
Secondary air temperature - 32.0°C
Axial location of traverse: exit swirl generator (x = 0.0 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	10.88	0.00	0.74	1.240	0.000	0.084
3.0	11.13	0.00	0.83	1.269	0.000	0.095
6.0	11.23	0.00	0.94	1.280	0.000	0.107
9.0	11.52	0.00	1.03	1.314	0.000	0.117
12.0	11.81	0.00	1.16	1.346	0.000	0.132
15.0	11.90	0.00	1.25	1.356	0.000	0.142
18.0	12.25	0.00	1.47	1.397	0.000	0.168
21.0	12.15	0.00	1.60	1.384	0.000	0.182
24.0	11.36	0.00	1.70	1.295	0.000	0.194
27.0	10.41	0.00	1.81	1.186	0.000	0.207
30.0	9.07	0.00	1.78	1.034	0.000	0.203
33.0	7.44	0.00	1.70	0.848	0.000	0.194
36.0	6.03	0.00	1.60	0.687	0.000	0.182
39.0	4.59	0.28	1.80	0.523	0.032	0.205
42.0	3.63	0.22	1.46	0.414	0.025	0.166
45.0	1.86	0.05	1.60	0.212	0.006	0.121
48.0	6.54	0.17	-0.81	0.745	0.020	-0.092
51.0	10.78	0.19	0.04	1.229	0.021	0.004
54.0	10.69	0.47	0.25	1.218	0.053	0.028
57.0	10.63	0.84	0.50	1.211	0.095	0.058
60.0	10.36	1.00	0.68	1.181	0.114	0.077
63.0	10.32	1.36	0.82	1.176	0.155	0.093
66.0	10.12	1.60	0.96	1.154	0.183	0.110
69.0	9.98	1.81	1.10	1.137	0.207	0.125
72.0	9.68	1.88	1.27	1.104	0.125	0.145
75.0	8.29	1.46	1.44	0.945	0.167	0.165
76.0	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-5 - Velocity profile data

Swirl setting - 1.0 high total air flow rate

Primary air temperature - 46.0°C

Secondary air temperature - 32.0°C

Axial location of traverse: exit swirl generator ($x = 0.0$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	48.69	0.00	2.24	1.312	0.000	0.060
3.0	50.00	0.00	2.66	1.348	0.000	0.072
6.0	51.70	0.00	3.20	1.393	0.000	0.086
9.0	52.93	0.00	3.67	1.426	0.000	0.099
12.0	53.31	0.00	4.23	1.437	0.000	0.114
15.0	53.89	0.00	4.72	1.452	0.000	0.127
18.0	53.26	0.00	5.32	1.435	0.000	0.143
21.0	51.15	0.00	5.85	1.378	0.000	0.158
24.0	47.15	0.00	6.17	1.270	0.000	0.166
27.0	42.29	0.00	6.25	1.140	0.000	0.168
30.0	36.47	0.00	6.10	0.983	0.000	0.164
33.0	30.04	0.00	5.86	0.810	0.000	0.158
36.0	23.93	0.00	5.19	0.645	0.000	0.140
39.0	18.12	0.00	4.60	0.488	0.000	0.124
42.0	12.49	1.09	3.72	0.336	0.029	0.100
45.0	7.93	1.18	0.98	0.214	0.032	0.026
48.0	15.09	3.35	-8.58	0.407	0.090	-0.231
51.0	44.12	8.98	-1.85	1.189	0.242	-0.050
54.0	44.44	11.49	-9.74	1.197	0.310	-0.020
57.0	43.92	14.27	0.29	1.183	0.385	0.008
60.0	43.68	16.77	0.87	1.177	0.452	0.024
63.0	43.89	19.36	1.51	1.183	0.522	0.041
66.0	44.34	21.62	2.17	1.195	0.583	0.058
69.0	44.92	23.38	2.75	1.211	0.630	0.074
72.0	44.89	24.37	2.64	1.210	0.657	0.071
75.0	43.29	17.93	4.35	1.166	0.483	0.117
76.0	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-6 - Velocity profile data

Swirl setting - 1.0 low total air flow rate

Primary air temperature - 62.0°C

Secondary air temperature - 33.0°C

Axial location of traverse: exit swirl generator ($x = 0.0$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	10.96	0.00	0.78	1.230	0.000	0.087
3.0	11.27	0.00	0.75	1.264	0.000	0.084
6.0	11.37	0.00	0.83	1.275	0.000	0.094
9.0	11.50	0.00	0.91	1.289	0.000	0.103
12.0	11.95	0.00	1.03	1.340	0.000	0.116
15.0	12.03	0.00	1.19	1.349	0.000	0.134
18.0	12.49	0.00	1.30	1.390	0.000	0.146
21.0	11.82	0.00	1.46	1.325	0.000	0.164
24.0	11.36	0.00	1.56	1.275	0.000	0.175
27.0	10.68	0.00	1.65	1.198	0.000	0.185
30.0	9.55	0.00	1.64	1.071	0.000	0.183
33.0	8.07	0.00	1.57	0.905	0.000	0.176
36.0	6.36	0.00	1.42	0.713	0.000	0.159
39.0	4.97	0.00	1.32	0.558	0.000	0.147
42.0	3.85	0.00	1.15	0.432	0.000	0.129
45.0	2.49	0.00	0.44	0.280	0.000	0.049
48.0	5.74	0.91	-1.38	0.644	0.102	-0.155
51.0	10.35	1.73	-0.37	1.160	0.194	-0.041
54.0	10.18	2.35	-0.12	1.141	0.263	-0.013
57.0	10.20	2.93	0.15	1.144	0.328	0.016
60.0	10.10	3.38	0.29	1.133	0.379	0.032
63.0	10.26	3.98	0.46	1.150	0.446	0.051
66.0	10.31	4.48	0.61	1.156	0.503	0.068
69.0	10.44	4.65	0.74	1.171	0.521	0.083
72.0	10.46	4.70	0.93	1.173	0.527	0.104
75.0	9.55	4.15	1.11	1.071	0.465	0.124
76.0	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-7 - Velocity profile data

Swirl setting - 2.0 high total air flow rate

Primary air temperature - 45.0°C

Secondary air temperature - 30.0°C

Axial location of traverse: exit swirl generator (x = 0.0 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	49.61	0.00	2.18	1.319	0.000	0.058
3.0	51.11	0.00	2.63	1.359	0.000	0.070
6.0	52.57	0.00	3.06	1.397	0.000	0.081
9.0	53.78	0.00	3.56	1.430	0.000	0.095
12.0	54.36	0.00	4.06	1.445	0.000	0.108
15.0	54.75	0.00	4.60	1.455	0.000	0.122
16.0	53.80	0.00	5.11	1.430	0.000	0.136
21.0	51.64	0.00	5.60	1.373	0.000	0.149
24.0	47.68	0.00	5.91	1.267	0.000	0.157
27.0	42.62	0.00	6.00	1.133	0.000	0.159
30.0	36.00	0.00	5.81	0.957	0.000	0.154
33.0	29.77	0.00	5.50	0.791	0.000	0.146
36.0	23.79	0.00	4.81	0.632	0.000	0.128
39.0	17.66	0.00	3.99	0.469	0.000	0.106
42.0	12.37	1.08	3.14	0.329	0.029	0.084
45.0	5.66	1.52	-2.82	0.150	0.040	-0.075
48.0	19.65	12.04	-9.05	0.522	0.320	-0.241
51.0	41.90	29.34	-0.02	1.114	0.780	-0.001
54.0	43.85	34.26	-3.03	1.166	0.911	-0.081
57.0	45.34	36.97	-1.78	1.205	0.983	-0.047
60.0	46.20	38.08	-0.83	1.228	1.012	-0.022
63.0	46.69	38.08	0.13	1.241	1.012	0.004
66.0	46.72	37.83	1.01	1.242	1.006	0.027
69.0	46.26	37.46	1.78	1.230	0.996	0.047
72.0	44.78	36.91	2.90	1.190	0.981	0.077
75.0	40.10	33.06	4.94	1.066	0.879	0.131
76.0	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-8 - Velocity profile data

Swirl setting - 2.0 low total air flow rate

Primary air temperature - 62.0°C

Secondary air temperature - 32.0°C

Axial location of traverse: exit swirl generator (x = 0.0 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	11.07	0.00	0.66	1.242	0.000	0.074
3.0	11.18	0.00	0.67	1.255	0.000	0.076
6.0	11.37	0.00	0.74	1.276	0.000	0.084
9.0	11.69	0.00	0.83	1.311	0.000	0.093
12.0	12.05	0.00	0.92	1.352	0.000	0.104
15.0	12.23	0.00	1.05	1.372	0.000	0.117
18.0	12.20	0.00	1.18	1.369	0.000	0.132
21.0	11.93	0.00	1.26	1.339	0.000	0.141
24.0	11.24	0.00	1.36	1.261	0.000	0.153
27.0	10.39	0.00	1.39	1.166	0.000	0.156
30.0	9.00	0.00	1.36	1.010	0.000	0.152
33.0	7.76	0.00	1.27	0.871	0.000	0.142
36.0	5.96	0.00	1.08	0.669	0.000	0.122
39.0	4.15	0.00	0.84	0.465	0.000	0.094
42.0	2.79	0.00	0.50	0.313	0.000	0.057
48.0	5.76	3.40	-2.04	0.647	0.381	-0.229
51.0	9.52	6.54	-1.08	1.068	0.734	-0.121
54.0	10.01	7.68	-0.83	1.124	0.862	-0.093
57.0	10.44	8.39	-0.49	1.171	0.942	-0.055
60.0	10.73	8.69	-0.24	1.204	0.975	-0.026
63.0	10.79	8.58	-0.01	1.211	0.963	-0.001
66.0	10.78	8.57	0.21	1.209	0.962	0.023
69.0	10.67	8.48	0.41	1.197	0.952	0.046
72.0	10.31	8.20	0.63	1.157	0.920	0.071
75.0	8.84	6.91	0.94	0.992	0.775	0.106
76.0	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-9 - Velocity profile data

Swirl setting - 3.0 high total air flow rate

Primary air temperature - 48.0°C

Secondary air temperature - 36.0°C

Axial location of traverse: exit swirl generator ($x = 0.0$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	49.23	0.00	2.89	1.262	0.000	0.074
3.0	50.54	0.00	3.22	1.295	0.000	0.083
6.0	52.23	0.00	3.74	1.339	0.000	0.096
9.0	53.24	0.00	4.26	1.365	0.000	0.109
12.0	54.03	0.00	4.81	1.385	0.000	0.123
15.0	54.80	0.00	5.41	1.405	0.000	0.139
18.0	54.45	0.00	5.96	1.395	0.000	0.153
21.0	52.81	0.00	6.49	1.353	0.000	0.166
24.0	49.65	0.00	6.81	1.272	0.000	0.175
27.0	44.74	0.00	6.97	1.147	0.000	0.179
30.0	39.54	0.00	6.89	1.013	0.000	0.177
33.0	32.93	0.00	6.45	0.844	0.000	0.165
36.0	27.01	0.00	5.72	0.692	0.000	0.147
39.0	21.05	0.00	4.85	0.539	0.000	0.124
42.0	15.66	0.55	3.96	0.401	0.014	0.102
45.0	9.52	2.77	0.53	0.244	0.071	0.014
48.0	16.74	15.07	-5.61	0.429	0.386	-0.144
51.0	29.59	34.04	-3.15	0.758	0.872	-0.081
54.0	34.59	44.27	-2.00	0.887	1.135	-0.051
57.0	40.64	51.09	-0.11	1.042	1.309	-0.003
60.0	45.50	54.23	1.53	1.166	1.390	0.039
63.0	49.54	55.40	3.18	1.270	1.420	0.081
66.0	52.41	54.65	4.51	1.343	1.401	0.116
69.0	53.07	53.06	5.37	1.360	1.360	0.138
72.0	52.93	52.01	6.56	1.357	1.333	0.168
75.0	48.49	47.65	8.46	1.243	1.221	0.217
76.0	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-10 - Velocity profile data

Swirl setting - 3.0 low total air flow rate

Primary air temperature - 59.0°C

Secondary air temperature - 30.0°C

Axial location of traverse: exit swirl generator (x = 0.0 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	9.74	0.00	2.42	1.179	0.000	0.292
3.0	9.57	0.00	2.42	1.157	0.000	0.292
6.0	9.38	0.00	2.45	1.135	0.000	0.297
9.0	9.44	0.00	2.48	1.141	0.000	0.300
12.0	9.44	0.00	2.55	1.142	0.000	0.308
15.0	9.35	0.00	2.61	1.130	0.000	0.316
18.0	9.05	0.00	2.69	1.094	0.000	0.326
21.0	9.11	0.00	2.82	1.103	0.000	0.341
24.0	8.58	0.00	2.96	1.037	0.000	0.358
27.0	7.88	0.00	3.03	0.953	0.000	0.367
30.0	6.61	0.00	3.28	0.800	0.000	0.397
33.0	5.64	0.00	3.45	0.682	0.000	0.417
48.0	4.02	3.88	1.70	0.486	0.470	0.206
51.0	6.48	7.38	1.08	0.784	0.893	0.131
54.0	7.62	9.79	1.06	0.922	1.184	0.128
57.0	8.87	11.36	1.24	1.073	1.374	0.150
60.0	10.00	11.92	1.57	1.209	1.441	0.190
63.0	10.84	12.25	1.91	1.311	1.482	0.232
66.0	11.46	12.16	2.19	1.386	1.471	0.265
69.0	11.78	11.78	2.40	1.425	1.424	0.291
72.0	11.68	11.60	2.67	1.412	1.403	0.323
75.0	10.56	10.20	3.01	1.278	1.234	0.365
76.0	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-11 - Velocity profile data

Swirl setting - 4.0 high total air flow rate
Primary air temperature - 48.0°C
Secondary air temperature - 37.0°C
Axial location of traverse: exit swirl generator ($x = 0.0$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	49.46	0.00	3.62	1.198	0.000	0.088
3.0	50.75	0.00	4.10	1.230	0.000	0.099
6.0	52.44	0.00	4.59	1.271	0.000	0.111
9.0	53.77	0.00	5.11	1.303	0.000	0.124
12.0	54.78	0.00	5.75	1.327	0.000	0.139
15.0	55.17	0.00	6.30	1.337	0.000	0.153
18.0	55.04	0.00	6.87	1.334	0.000	0.166
21.0	53.68	0.00	7.52	1.301	0.000	0.182
24.0	51.48	0.00	8.10	1.247	0.000	0.196
27.0	46.75	0.00	8.21	1.133	0.000	0.199
30.0	41.80	0.00	8.04	1.013	0.000	0.195
33.0	35.94	0.00	7.59	0.871	0.000	0.184
36.0	30.35	0.00	6.97	0.735	0.000	0.169
39.0	24.55	1.50	6.33	0.595	0.036	0.153
42.0	19.64	2.06	5.67	0.476	0.050	0.137
45.0	14.90	0.78	5.33	0.361	0.019	0.129
48.0	10.26	5.80	2.21	0.249	0.141	0.054
51.0	18.25	26.56	-1.07	0.442	0.643	-0.026
54.0	26.98	44.89	-0.64	0.654	1.088	-0.015
57.0	36.25	59.15	1.52	0.878	1.433	0.037
60.0	46.05	67.00	4.63	1.116	1.623	0.112
63.0	54.04	70.42	7.72	1.309	1.706	0.187
66.0	58.99	70.30	10.00	1.429	1.703	0.242
69.0	62.01	68.87	11.47	1.503	1.669	0.278
72.0	63.65	65.91	12.44	1.542	1.597	0.302
75.0	60.69	61.54	13.78	1.471	1.491	0.334
76.0	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-12 - Velocity profile data

Swirl setting - 4.0 low total air flow rate

Primary air temperature - 59.0°C

Secondary air temperature - 31.0°C

Axial location of traverse: exit swirl generator ($x = 0.0$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	10.78	0.00	0.91	1.225	0.000	0.104
3.0	10.67	0.00	0.93	1.213	0.000	0.105
6.0	10.83	0.00	0.96	1.230	0.000	0.110
9.0	11.03	0.00	1.03	1.254	0.000	0.117
12.0	11.17	0.00	1.13	1.269	0.000	0.129
15.0	11.12	0.00	1.27	1.263	0.000	0.145
18.0	10.90	0.00	1.38	1.239	0.000	0.157
21.0	11.03	0.00	1.60	1.253	0.000	0.181
24.0	10.79	0.00	1.81	1.226	0.000	0.206
27.0	10.02	0.00	1.89	1.139	0.000	0.215
30.0	9.00	0.00	1.87	1.023	0.000	0.213
33.0	7.72	0.00	1.80	0.877	0.000	0.205
36.0	6.54	0.00	1.72	0.744	0.000	0.196
39.0	4.76	0.80	1.66	0.541	0.091	0.189
42.0	3.80	0.88	1.47	0.432	0.100	0.168
45.0	2.84	0.47	1.51	0.322	0.054	0.171
48.0	1.93	1.05	0.87	0.220	0.119	0.098
51.0	4.02	6.03	-0.03	0.457	0.685	-0.003
54.0	5.84	9.95	0.12	0.663	1.130	0.014
57.0	7.87	12.94	0.57	0.894	1.471	0.065
60.0	10.00	14.71	1.15	1.136	1.672	0.131
63.0	11.71	15.54	1.74	1.331	1.766	0.198
66.0	12.89	15.53	2.19	1.465	1.765	0.249
69.0	13.46	15.21	2.47	1.530	1.729	0.281
72.0	13.81	14.65	2.70	1.569	1.665	0.306
75.0	13.09	13.51	3.00	1.488	1.535	0.341
76.0	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-13 - Velocity profile data

Swirl setting - 4.5 high total air flow rate

Primary air temperature - 45.0°C

Secondary air temperature - 34.0°C

Axial location of traverse: exit swirl generator ($x = 0.0$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	49.20	0.00	3.57	1.234	0.000	0.090
3.0	50.53	0.00	3.99	1.268	0.000	0.100
6.0	52.15	0.00	4.52	1.308	0.000	0.113
9.0	53.80	0.00	5.07	1.350	0.000	0.127
12.0	54.96	0.00	5.65	1.379	0.000	0.142
15.0	55.78	0.00	6.28	1.400	0.000	0.157
18.0	55.59	0.00	6.95	1.395	0.000	0.174
21.0	54.67	0.00	7.53	1.372	0.000	0.189
24.0	52.18	0.00	8.00	1.309	0.000	0.201
27.0	48.35	0.00	8.22	1.213	0.000	0.206
30.0	43.10	0.00	8.13	1.081	0.000	0.204
33.0	37.51	0.00	7.65	0.941	0.000	0.192
36.0	31.48	0.55	7.13	0.790	0.014	0.179
39.0	25.06	1.75	6.29	0.629	0.044	0.158
42.0	20.08	2.04	5.65	0.504	0.051	0.142
45.0	10.56	0.83	6.33	0.265	0.021	0.159
48.0	9.53	4.63	2.93	0.239	0.116	0.074
51.0	16.42	24.61	-0.94	0.412	0.618	-0.024
54.0	24.05	42.00	-0.79	0.604	1.054	-0.020
57.0	33.25	56.44	1.20	0.834	1.416	0.030
60.0	41.97	65.87	4.11	1.053	1.653	0.103
63.0	50.69	69.77	7.25	1.272	1.750	0.182
66.0	56.56	70.35	9.87	1.419	1.765	0.246
69.0	60.12	69.16	11.47	1.508	1.735	0.288
72.0	61.56	67.17	12.69	1.544	1.685	0.318
75.0	58.93	62.10	14.03	1.479	1.558	0.352
76.0	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-14 - Velocity profile data

Swirl setting - 4.5 low total air flow rate

Primary air temperature - 60.0°C

Secondary air temperature - 32.0°C

Axial location of traverse: exit swirl generator (x = 0.0 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	10.93	0.00	0.93	1.206	0.000	0.102
3.0	10.74	0.00	0.93	1.185	0.000	0.103
6.0	10.84	0.00	1.02	1.196	0.000	0.112
9.0	10.79	0.00	1.04	1.190	0.000	0.114
12.0	10.94	0.00	1.15	1.207	0.000	0.127
15.0	11.03	0.00	1.26	1.217	0.000	0.139
18.0	11.27	0.00	1.42	1.244	0.000	0.156
21.0	10.94	0.00	1.60	1.207	0.000	0.176
24.0	10.50	0.00	1.70	1.159	0.000	0.188
27.0	9.98	0.00	1.83	1.101	0.000	0.202
30.0	9.27	0.00	1.82	1.023	0.000	0.201
33.0	7.75	0.00	1.74	0.855	0.000	0.192
36.0	6.53	0.74	1.65	0.720	0.082	0.182
39.0	4.90	1.07	1.58	0.541	0.118	0.174
42.0	3.90	1.34	1.41	0.430	0.148	0.156
45.0	2.77	1.15	1.50	0.305	0.127	0.166
48.0	2.32	0.99	1.07	0.256	0.109	0.118
51.0	3.87	5.52	0.04	0.427	0.610	0.005
54.0	5.72	9.48	0.14	0.631	1.046	0.016
57.0	7.80	12.98	0.56	0.861	1.432	0.062
60.0	10.10	15.37	1.20	1.114	1.696	0.132
63.0	12.11	16.43	1.85	1.337	1.813	0.204
66.0	13.55	16.74	2.27	1.495	1.847	0.250
69.0	14.33	16.43	2.79	1.581	1.812	0.308
72.0	14.75	15.87	3.03	1.627	1.751	0.334
75.0	14.02	14.62	3.38	1.547	1.613	0.372
76.0	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-15 - Velocity profile data

Swirl setting - 0.0 high total air flow rate

Primary air temperature - 32.5°C

Secondary air temperature - 32.5°C

Axial location of traverse: exit quarl (x = 0.42 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
-75.0	13.42	0.00	-0.58	0.367	0.000	-0.016
-50.0	19.86	0.00	-1.87	0.543	0.000	-0.051
-25.0	23.85	0.00	-2.30	0.652	0.000	-0.063
0.0	26.13	0.00	2.49	0.714	0.000	0.068
5.0	26.17	0.00	2.53	0.715	0.000	0.069
10.0	26.33	0.00	2.61	0.719	0.000	0.071
15.0	26.11	0.00	2.61	0.713	0.000	0.071
20.0	25.76	0.00	2.62	0.704	0.000	0.071
25.0	25.25	0.00	2.60	0.690	0.000	0.071
30.0	24.73	0.00	2.60	0.676	0.000	0.071
35.0	24.16	0.00	2.56	0.660	0.000	0.070
40.0	23.62	0.00	2.47	0.645	0.000	0.068
45.0	23.21	0.00	2.47	0.634	0.000	0.067
50.0	22.76	0.00	2.41	0.622	0.000	0.066
55.0	22.41	0.00	2.45	0.613	0.000	0.067
60.0	22.06	0.00	2.51	0.603	0.000	0.069
65.0	21.69	0.00	2.56	0.593	0.000	0.070
70.0	21.26	0.00	2.71	0.581	0.000	0.074
75.0	20.56	0.00	2.78	0.562	0.000	0.076
80.0	19.75	0.00	2.97	0.540	0.000	0.081
85.0	19.06	0.00	3.10	0.521	0.000	0.085
90.0	17.75	0.00	3.28	0.485	0.000	0.090
95.0	16.65	0.00	3.29	0.455	0.000	0.090
100.0	15.12	0.00	3.26	0.413	0.000	0.089
105.0	14.00	0.00	3.23	0.383	0.000	0.088
110.0	12.61	0.00	3.10	0.345	0.000	0.085

Table A1-15 (cont'd)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
115.0	10.64	0.00	3.08	0.291	0.000	0.084
120.0	9.24	0.00	2.87	0.253	0.000	0.079
125.0	7.40	0.00	2.91	0.202	0.000	0.080
130.0	6.50	0.00	2.69	0.178	0.000	0.074
135.0	5.46	0.00	2.13	0.149	0.000	0.058
140.0	4.26	0.00	1.87	0.116	0.000	0.051
145.0	3.30	0.00	1.24	0.090	0.000	0.034
150.0	1.99	0.37	1.11	0.054	0.010	0.030
155.0	1.94	0.49	0.45	0.053	0.013	0.012

Table A1-16 - Velocity profile data

Swirl setting - 0.0 low total air flow rate

Primary air temperature - 33.9°C

Secondary air temperature - 33.9°C

Axial location of traverse: exit quarl (x = 0.42 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
-75.0	3.58	0.00	-0.05	0.418	0.000	-0.005
-50.0	5.89	0.00	-0.25	0.687	0.000	-0.029
-25.0	7.27	0.00	-0.58	0.849	0.000	-0.068
0.0	6.59	0.00	0.69	0.769	0.000	0.080
5.0	6.51	0.00	0.73	0.760	0.000	0.085
10.0	5.90	0.00	0.60	0.688	0.000	0.070
15.0	5.79	0.00	0.57	0.676	0.000	0.067
20.0	5.45	0.00	0.61	0.637	0.000	0.071
25.0	5.38	0.00	0.56	0.628	0.000	0.065
30.0	4.98	0.00	0.51	0.582	0.000	0.060
35.0	4.94	0.00	0.47	0.577	0.000	0.055
40.0	4.64	0.00	0.41	0.542	0.000	0.048
45.0	4.64	0.00	0.43	0.542	0.000	0.050
50.0	4.59	0.00	0.46	0.536	0.000	0.054
55.0	4.50	0.00	0.49	0.525	0.000	0.057
60.0	4.22	0.00	0.41	0.493	0.000	0.048
65.0	4.27	0.00	0.46	0.498	0.000	0.053
70.0	3.63	0.00	0.48	0.424	0.000	0.056
75.0	3.75	0.00	0.44	0.437	0.000	0.052
80.0	3.62	0.00	0.55	0.423	0.000	0.064
85.0	3.50	0.00	0.59	0.408	0.000	0.069
90.0	3.20	0.00	0.46	0.374	0.000	0.054
95.0	3.01	0.00	0.40	0.351	0.000	0.047
100.0	3.45	0.00	0.52	0.402	0.000	0.061
105.0	2.65	0.00	0.33	0.309	0.000	0.038
110.0	2.31	0.00	0.37	0.269	0.000	0.043
115.0	2.30	0.00	0.42	0.268	0.000	0.049

Table A1-16 (con't)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
120.0	2.11	0.00	0.38	0.247	0.000	0.044
125.0	1.82	0.00	0.21	0.212	0.000	0.024
130.0	1.76	0.00	0.09	0.206	0.000	0.010
135.0	2.32	0.00	0.21	0.271	0.000	0.024
140.0	1.86	0.00	-0.09	0.217	0.000	-0.011

Table A1-17 - Velocity profile data

Swirl setting - 0.5 high total air flow rate

Primary air temperature - 36.1°C

Secondary air temperature - 36.1°C

Axial location of traverse: exit quarl (x = 0.42 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
-75.0	12.90	2.39	-0.09	0.351	0.065	-0.003
-50.0	17.20	2.26	-1.28	0.468	0.062	-0.035
-25.0	20.89	1.53	-2.17	0.569	0.042	-0.059
0.0	24.63	0.43	3.01	0.671	0.012	0.082
5.0	25.14	0.44	3.20	0.685	0.012	0.087
10.0	25.55	0.00	3.35	0.696	0.000	0.091
15.0	25.54	0.22	3.36	0.696	0.006	0.092
20.0	25.64	0.22	3.42	0.698	0.006	0.093
25.0	25.42	0.27	3.50	0.692	0.007	0.095
30.0	25.17	0.35	3.52	0.685	0.010	0.096
35.0	24.77	0.48	3.48	0.675	0.013	0.095
40.0	24.41	0.51	3.40	0.665	0.014	0.093
45.0	23.86	0.83	3.31	0.650	0.023	0.090
50.0	23.04	0.84	3.21	0.627	0.023	0.087
55.0	22.57	1.26	3.10	0.615	0.034	0.084
60.0	22.09	1.51	2.97	0.602	0.041	0.081
65.0	21.70	1.78	3.05	0.591	0.049	0.083
70.0	21.06	2.03	3.03	0.574	0.055	0.082
75.0	20.40	2.14	3.10	0.556	0.058	0.085
80.0	19.78	2.43	3.15	0.539	0.066	0.086
85.0	18.61	2.55	3.35	0.507	0.069	0.091
90.0	17.42	2.60	3.36	0.474	0.071	0.092
95.0	16.16	2.91	3.39	0.440	0.079	0.092
100.0	15.07	2.79	3.50	0.410	0.076	0.095
105.0	13.13	2.74	3.49	0.358	0.075	0.095
110.0	11.72	2.71	3.39	0.319	0.074	0.092
115.0	10.22	3.03	3.28	0.278	0.082	0.089

Table A1-17 (cont'd)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
120.0	8.47	2.84	3.31	0.231	0.077	0.090
125.0	7.17	2.87	3.18	0.195	0.078	0.086
130.0	5.11	2.49	3.04	0.139	0.068	0.083
135.0	3.96	2.11	2.69	0.108	0.057	0.073
140.0	2.79	1.96	2.65	0.076	0.053	0.072

Table A1-18 - Velocity profile data

Swirl setting - 0.5 low total air flow rate

Primary air temperature - 39.7°C

Secondary air temperature - 39.7°C

Axial location of traverse: exit quarl ($x = 0.42$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
-75.0	3.94	0.93	0.01	0.464	0.109	0.001
-50.0	5.87	0.77	-0.23	0.691	0.091	-0.027
-25.0	6.71	0.65	-0.45	0.790	0.076	-0.053
0.0	6.58	0.63	0.49	0.775	0.075	0.058
5.0	6.47	0.45	0.72	0.761	0.053	0.085
10.0	6.13	0.43	0.77	0.722	0.050	0.090
15.0	6.04	0.44	0.83	0.710	0.052	0.098
20.0	5.62	0.44	0.77	0.662	0.052	0.091
25.0	5.48	0.43	0.72	0.645	0.051	0.084
30.0	5.17	0.48	0.58	0.608	0.056	0.068
35.0	4.93	0.45	0.36	0.580	0.053	0.042
40.0	4.72	0.37	0.37	0.555	0.044	0.043
45.0	4.72	0.33	0.26	0.556	0.039	0.031
50.0	4.63	0.31	0.29	0.545	0.036	0.034
55.0	4.40	0.31	0.22	0.518	0.036	0.026
60.0	4.35	0.27	0.27	0.512	0.032	0.032
65.0	4.41	0.04	0.26	0.519	0.005	0.031
70.0	4.26	0.04	0.26	0.502	0.004	0.031
75.0	4.26	0.04	0.40	0.501	0.004	0.047
80.0	4.23	0.04	0.44	0.498	0.004	0.051
85.0	4.11	0.07	0.33	0.484	0.008	0.038
90.0	3.89	0.07	0.48	0.457	0.008	0.056
95.0	3.55	0.06	0.41	0.418	0.007	0.048
100.0	3.40	0.06	0.35	0.400	0.007	0.041
105.0	2.88	0.25	0.40	0.339	0.030	0.047
110.0	2.58	0.23	0.33	0.304	0.027	0.039

Table A1-18 (cont'd)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
115.0	2.54	0.27	0.29	0.299	0.031	0.034
120.0	2.05	0.47	0.19	0.241	0.056	0.022
125.0	1.04	0.59	-0.10	0.123	0.069	-0.011
130.0	1.07	0.91	-0.21	0.126	0.107	-0.025
135.0	0.44	1.22	-0.29	0.052	0.144	-0.034

Table A1-19 - Velocity profile data

Swirl setting - 1.0 high total air flow rate

Primary air temperature - 38.4°C

Secondary air temperature - 38.4°C

Axial location of traverse: exit quarl (x = 0.42 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
-75.0	5.63	3.59	-0.47	0.152	0.097	-0.013
-50.0	7.47	3.72	-2.41	0.202	0.100	-0.065
-25.0	8.99	3.24	-4.45	0.243	0.087	-0.120
0.0	9.03	2.28	5.87	0.244	0.062	0.159
5.0	9.45	2.18	6.14	0.255	0.059	0.166
10.0	9.95	2.03	6.21	0.269	0.055	0.168
15.0	10.14	1.16	6.84	0.274	0.031	0.185
20.0	10.96	1.25	6.81	0.296	0.034	0.184
25.0	10.98	0.86	7.14	0.296	0.023	0.193
30.0	11.69	0.37	7.25	0.316	0.010	0.196
35.0	12.25	0.17	7.62	0.331	0.005	0.206
40.0	12.93	0.56	8.47	0.349	0.015	0.229
45.0	13.48	0.59	8.15	0.364	0.016	0.220
50.0	14.14	0.74	8.37	0.382	0.020	0.226
55.0	14.06	0.93	8.92	0.380	0.025	0.241
60.0	14.19	0.99	9.25	0.383	0.027	0.250
65.0	14.41	1.39	9.47	0.389	0.037	0.256
70.0	14.47	1.67	9.53	0.391	0.045	0.257
75.0	14.54	1.84	9.89	0.393	0.050	0.267
80.0	14.33	2.01	10.10	0.387	0.054	0.273
85.0	14.02	2.35	10.17	0.379	0.063	0.275
90.0	13.64	2.78	10.49	0.368	0.075	0.283
95.0	13.67	3.46	10.59	0.369	0.093	0.286
100.0	14.07	4.03	10.36	0.380	0.109	0.280
105.0	13.09	3.78	10.97	0.353	0.102	0.296
110.0	12.75	3.95	10.75	0.344	0.107	0.290

Table A1-19 (cont'd)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
115.0	12.74	4.26	10.72	0.344	0.115	0.289
120.0	12.75	5.02	10.48	0.344	0.136	0.283
125.0	12.43	5.33	10.53	0.336	0.144	0.284
130.0	12.36	5.37	10.71	0.334	0.145	0.289
135.0	12.21	5.87	10.65	0.330	0.159	0.288
140.0	11.91	6.41	10.38	0.322	0.173	0.280
145.0	11.37	6.44	10.36	0.307	0.174	0.280
150.0	11.22	6.48	10.39	0.303	0.175	0.281
155.0	11.14	6.96	10.14	0.301	0.188	0.274
160.0	10.66	7.13	9.95	0.288	0.193	0.269
165.0	10.13	7.47	9.51	0.274	0.202	0.257
170.0	9.56	7.41	9.14	0.258	0.200	0.247
175.0	9.24	7.40	8.58	0.249	0.200	0.232
180.0	8.84	7.47	8.38	0.239	0.202	0.226

Table A1-20 - Velocity profile data

Swirl setting - 2.0 high total air flow rate

Primary air temperature - 41.2°C

Secondary air temperature - 41.2°C

Axial location of traverse: exit quarl ($x = 0.42$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
-75.0	-4.62	2.06	1.53	-0.123	0.055	0.041
0.0	4.26	0.00	0.00	0.113	0.000	0.000
5.0	4.26	0.28	-3.15	0.113	0.008	-0.084
10.0	4.62	0.08	-2.96	0.123	0.002	-0.079
15.0	4.92	0.13	-2.74	0.131	0.003	-0.073
20.0	5.13	0.35	-2.45	0.137	0.009	-0.065
25.0	5.39	0.05	-2.30	0.144	0.001	-0.061
30.0	5.98	0.19	-1.76	0.159	0.005	-0.047
35.0	6.12	0.09	-1.34	0.163	0.002	-0.036
40.0	6.52	0.26	-0.94	0.174	0.007	-0.025
45.0	6.45	0.11	-0.51	0.172	0.003	-0.014
50.0	6.14	0.25	-0.37	0.164	0.007	-0.010
55.0	6.18	0.27	-0.13	0.165	0.007	-0.003
60.0	6.23	0.44	0.35	0.166	0.012	0.009
65.0	5.61	0.19	0.65	0.150	0.005	0.017
70.0	4.85	0.19	0.94	0.129	0.005	0.025
75.0	5.14	0.34	1.30	0.137	0.009	0.035
80.0	4.63	0.40	1.30	0.123	0.011	0.035
85.0	0.00	0.00	0.00	0.000	0.000	0.000
90.0	-1.10	1.31	1.14	-0.029	0.035	0.030
95.0	-1.32	1.51	1.38	-0.035	0.040	0.037
100.0	-2.25	1.89	1.49	-0.060	0.050	0.040
105.0	-2.30	1.90	1.86	-0.061	0.051	0.050
145.0	4.29	2.85	2.72	0.114	0.076	0.073
150.0	6.47	3.37	3.06	0.172	0.090	0.082
155.0	8.57	3.81	3.69	0.228	0.102	0.098

Table A1-20 (cont'd)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
160.0	10.94	4.31	4.34	0.292	0.115	0.116
165.0	13.25	5.03	5.73	0.353	0.134	0.153
170.0	15.40	5.85	6.59	0.410	0.156	0.175
175.0	17.03	6.64	7.64	0.454	0.177	0.204
180.0	17.72	7.45	8.35	0.472	0.199	0.223
185.0	16.53	7.02	8.89	0.440	0.187	0.237
190.0	12.61	5.38	10.32	0.336	0.143	0.275

Table A1-21 - Velocity profile data

Swirl setting - 2.0 low total air flow rate

Primary air temperature - 34.1°C

Secondary air temperature - 34.1°C

Axial location of traverse: exit quarl (x = 0.42 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	0.00	0.00	0.00	0.000	0.000	0.000
120.0	0.05	0.85	0.39	0.006	0.104	0.048
140.0	0.90	0.32	0.70	0.110	0.039	0.086
145.0	1.16	0.45	0.69	0.142	0.055	0.085
150.0	1.68	0.58	0.70	0.206	0.071	0.086
155.0	1.90	0.81	0.85	0.232	0.100	0.104
160.0	2.64	0.94	0.94	0.324	0.115	0.115
165.0	3.08	1.09	1.13	0.378	0.134	0.139
170.0	3.76	1.40	1.37	0.460	0.172	0.167
175.0	3.90	1.31	1.54	0.478	0.160	0.189
180.0	3.99	1.45	1.72	0.488	0.178	0.210
185.0	3.59	1.54	1.85	0.439	0.188	0.226
190.0	2.41	1.15	1.91	0.295	0.141	0.234

Table A1-22 - Velocity profile data

Swirl setting - 3.0 high total air flow rate

Primary air temperature - 39.3°C

Secondary air temperature - 39.3°C

Axial location of traverse: exit quarl (x = 0.42 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
-75.0	-4.41	3.70	2.02	-0.119	0.100	0.054
0.0	-2.76	1.12	-1.59	-0.074	0.030	-0.043
5.0	-2.67	1.00	-1.54	-0.072	0.027	-0.041
10.0	-3.57	0.96	-0.78	-0.096	0.026	-0.021
15.0	-4.15	0.92	-0.40	-0.112	0.025	-0.011
20.0	-4.18	0.37	0.02	-0.113	0.010	0.001
25.0	-4.60	0.20	0.51	-0.124	0.005	0.014
30.0	-4.44	0.22	0.80	-0.120	0.006	0.022
35.0	-4.71	0.62	1.07	-0.127	0.017	0.029
40.0	-5.20	1.28	1.23	-0.140	0.034	0.033
45.0	-5.20	1.67	1.52	-0.140	0.045	0.041
50.0	-5.52	2.07	1.52	-0.149	0.056	0.041
55.0	-5.62	2.64	1.55	-0.151	0.071	0.042
60.0	-5.64	3.05	1.77	-0.152	0.082	0.048
65.0	-5.74	3.46	1.86	-0.155	0.093	0.050
70.0	-5.74	3.87	1.94	-0.154	0.104	0.052
75.0	-5.90	4.21	2.06	-0.159	0.113	0.055
80.0	-5.61	4.71	2.06	-0.151	0.127	0.055
85.0	-5.50	4.95	2.18	-0.148	0.133	0.059
90.0	-5.47	5.20	2.15	-0.147	0.140	0.058
95.0	-4.95	5.40	2.14	-0.133	0.145	0.058
100.0	-4.46	5.51	2.23	-0.120	0.148	0.060
105.0	-3.78	5.36	2.69	-0.102	0.144	0.072
110.0	-2.61	5.02	2.47	-0.070	0.135	0.066
115.0	-1.63	4.61	2.55	-0.044	0.124	0.069
125.0	0.26	3.02	2.43	0.007	0.081	0.065

Table A1-22 (cont'd)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
130.0	1.45	3.94	2.09	0.039	0.106	0.056
135.0	3.38	4.82	2.16	0.091	0.130	0.058
140.0	6.22	6.22	2.39	0.168	0.168	0.064
145.0	8.53	6.47	3.34	0.230	0.174	0.090
150.0	11.19	7.33	3.98	0.302	0.197	0.107
155.0	13.78	7.79	4.82	0.371	0.210	0.130
160.0	15.86	7.56	5.65	0.427	0.204	0.152
165.0	18.00	7.83	6.41	0.485	0.211	0.173
170.0	19.20	8.35	7.15	0.517	0.225	0.193
175.0	19.67	8.63	7.78	0.530	0.233	0.209
180.0	18.80	8.37	8.27	0.506	0.225	0.223
185.0	16.92	7.89	8.59	0.456	0.213	0.231
190.0	11.74	5.20	8.44	0.316	0.140	0.227

Table A1-23 - Velocity profile data

Swirl setting - 3.0 low total air flow rate

Primary air temperature - 36.6°C

Secondary air temperature - 36.6°C

Axial location of traverse: exit quarl (x = 0.42 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
-75.0	-1.23	0.98	0.07	-0.151	0.120	0.008
-50.0	-1.00	0.71	0.26	-0.122	0.087	0.031
-25.0	-0.98	0.44	0.19	-0.120	0.054	0.023
0.0	-0.99	0.24	0.05	-0.122	0.030	0.006
5.0	-1.11	0.15	0.10	-0.136	0.018	0.012
10.0	-1.12	0.05	0.10	-0.137	0.006	0.012
15.0	-1.20	0.04	0.18	-0.147	0.005	0.022
20.0	-1.10	0.00	0.24	-0.135	0.000	0.029
25.0	-1.19	0.12	0.24	-0.145	0.015	0.029
30.0	-1.58	0.39	0.33	-0.193	0.048	0.041
35.0	-1.29	0.34	0.37	-0.158	0.042	0.046
40.0	-1.08	0.45	0.36	-0.132	0.056	0.044
45.0	-1.41	0.62	0.41	-0.173	0.076	0.051
50.0	-1.27	0.59	0.39	-0.156	0.073	0.048
55.0	-1.37	0.68	0.46	-0.168	0.084	0.057
60.0	-1.33	0.83	0.56	-0.163	0.102	0.069
65.0	-1.57	0.83	0.51	-0.192	0.102	0.062
70.0	-1.40	1.00	0.47	-0.172	0.122	0.058
75.0	-1.24	1.00	0.47	-0.152	0.123	0.057
80.0	-1.25	1.08	0.51	-0.153	0.133	0.062
85.0	-1.25	1.16	0.54	-0.153	0.143	0.066
90.0	-1.29	1.25	0.41	-0.158	0.153	0.050
95.0	-1.08	1.36	0.40	-0.132	0.166	0.050
100.0	-0.87	1.19	0.39	-0.107	0.146	0.048
105.0	-0.82	1.33	0.62	-0.100	0.162	0.076
110.0	-0.41	0.98	0.68	-0.051	0.120	0.084
115.0	-0.34	0.97	0.77	-0.042	0.119	0.094

Table A1-23 (cont'd)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
120.0	-0.13	0.84	0.69	-0.016	0.103	0.085
125.0	0.06	0.88	0.62	0.008	0.108	0.076
130.0	0.28	0.74	0.55	0.034	0.091	0.068
135.0	0.72	1.03	0.65	0.088	0.126	0.080
140.0	1.40	1.53	0.61	0.172	0.187	0.075
145.0	1.95	1.63	0.77	0.238	0.199	0.094
150.0	2.57	1.74	0.88	0.315	0.213	0.108
155.0	3.14	1.74	1.09	0.384	0.213	0.134
160.0	3.55	1.75	1.26	0.435	0.214	0.154
165.0	4.08	1.92	1.36	0.499	0.235	0.166
170.0	4.29	1.89	1.53	0.526	0.232	0.187
175.0	4.38	1.95	1.66	0.536	0.239	0.203
180.0	4.23	1.97	1.80	0.518	0.241	0.220
185.0	3.51	1.67	1.83	0.429	0.205	0.224
190.0	2.40	1.36	1.78	0.294	0.166	0.218

Table A1-24 - Velocity profile data

Swirl setting - 4.0 high total air flow rate

Primary air temperature - 43.0°C

Secondary air temperature - 43.0°C

Axial location of traverse: exit quarl ($x = 0.42$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
-75.0	-6.74	6.33	1.99	-0.179	0.168	0.053
-50.0	-7.62	4.67	1.43	-0.203	0.124	0.038
-25.0	-8.66	2.32	0.47	-0.231	0.062	0.012
0.0	-9.05	0.24	0.55	-0.241	0.006	0.015
5.0	-9.03	0.63	0.68	-0.240	0.017	0.018
10.0	-9.20	1.05	1.06	-0.245	0.028	0.028
15.0	-9.14	1.61	1.23	-0.243	0.043	0.033
20.0	-9.17	2.27	1.27	-0.244	0.060	0.034
25.0	-9.02	2.76	1.57	-0.240	0.073	0.042
30.0	-8.82	3.35	1.57	-0.235	0.089	0.042
35.0	-8.76	3.99	1.75	-0.233	0.106	0.047
40.0	-8.53	4.44	1.85	-0.227	0.118	0.049
45.0	-8.46	4.99	1.92	-0.225	0.133	0.051
50.0	-8.19	5.49	2.03	-0.218	0.146	0.054
55.0	-8.04	5.95	2.15	-0.214	0.158	0.057
60.0	-7.98	6.35	2.24	-0.212	0.169	0.059
65.0	-7.79	6.90	2.24	-0.207	0.184	0.060
70.0	-7.63	7.30	2.20	-0.203	0.194	0.059
75.0	-7.50	7.52	2.21	-0.200	0.200	0.059
80.0	-7.29	7.76	2.32	-0.194	0.207	0.062
85.0	-6.82	7.98	2.33	-0.181	0.212	0.062
90.0	-6.48	8.06	2.43	-0.173	0.215	0.065
95.0	-5.94	8.12	2.38	-0.158	0.216	0.063
100.0	-5.23	8.05	2.35	-0.139	0.214	0.063
105.0	-4.19	7.73	2.41	-0.112	0.206	0.064
110.0	-3.58	7.68	2.54	-0.095	0.204	0.068

Table A1-24 (cont'd)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
115.0	-2.27	7.20	2.63	-0.060	0.192	0.070
120.0	-0.84	6.37	2.53	-0.022	0.170	0.067
125.0	0.43	5.40	2.63	0.012	0.144	0.070
130.0	1.16	4.67	3.17	0.031	0.124	0.084
135.0	3.67	7.27	2.44	0.098	0.194	0.065
140.0	6.33	7.96	2.86	0.169	0.212	0.076
145.0	9.00	8.78	3.56	0.239	0.234	0.095
150.0	12.45	9.80	4.41	0.331	0.261	0.117
155.0	15.14	10.29	5.32	0.403	0.274	0.142
160.0	17.84	10.63	6.35	0.475	0.283	0.169
165.0	19.95	10.97	7.25	0.531	0.292	0.193
170.0	21.40	10.86	8.26	0.570	0.289	0.220
175.0	21.79	10.63	8.82	0.580	0.283	0.235
180.0	20.87	10.09	9.18	0.555	0.269	0.244
185.0	18.46	8.92	9.67	0.491	0.237	0.257
190.0	13.17	6.42	9.13	0.350	0.171	0.243

Table A1-25 - Velocity profile data

Swirl setting - 4.0 low total air flow rate

Primary air temperature - 35.3°C

Secondary air temperature - 35.3°C

Axial location of traverse: exit quarl (x = 0.42 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
-75.0	-1.69	1.03	0.27	-0.207	0.127	0.034
-50.0	-2.08	1.08	0.13	-0.255	0.133	0.016
-25.0	-2.22	0.53	-0.04	-0.272	0.065	-0.005
0.0	-2.13	0.11	0.27	-0.261	0.014	0.033
5.0	-2.02	0.21	0.26	-0.248	0.026	0.032
10.0	-2.28	0.30	0.45	-0.279	0.037	0.055
15.0	-2.36	0.57	0.46	-0.289	0.070	0.057
20.0	-2.18	0.54	0.47	-0.268	0.066	0.058
25.0	-2.22	0.76	0.42	-0.273	0.093	0.051
30.0	-2.07	0.89	0.47	-0.253	0.109	0.058
35.0	-1.93	0.96	0.47	-0.236	0.118	0.057
40.0	-1.96	1.09	0.50	-0.240	0.134	0.061
45.0	-1.98	1.23	0.52	-0.243	0.150	0.064
50.0	-1.84	1.29	0.67	-0.226	0.158	0.082
55.0	-1.98	1.38	0.55	-0.243	0.169	0.067
60.0	-0.80	1.51	0.62	-0.221	0.185	0.076
65.0	-1.82	1.63	0.59	-0.224	0.200	0.073
70.0	-1.80	1.58	0.64	-0.220	0.194	0.079
75.0	-1.85	1.84	0.63	-0.227	0.225	0.077
80.0	-1.63	1.66	0.74	-0.200	0.203	0.091
85.0	-1.47	1.72	0.65	-0.180	0.210	0.079
90.0	-1.47	1.73	0.57	-0.180	0.213	0.070
95.0	-1.24	1.63	0.71	-0.152	0.200	0.087
100.0	-1.18	1.81	0.66	-0.145	0.221	0.081
105.0	-0.91	1.74	0.64	-0.111	0.213	0.078
110.0	-0.86	1.71	0.61	-0.106	0.209	0.075

Table A1-25 (cont'd)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
115.0	-0.47	1.56	0.57	-0.058	0.191	0.070
120.0	-0.13	1.22	0.71	-0.016	0.150	0.087
125.0	0.08	1.24	0.67	0.009	0.152	0.082
135.0	0.79	1.47	0.88	0.096	0.180	0.108
140.0	1.85	2.42	0.79	0.227	0.297	0.097
145.0	2.22	2.01	0.89	0.272	0.246	0.109
150.0	3.17	2.59	0.99	0.389	0.317	0.121
155.0	3.82	2.50	1.17	0.468	0.306	0.143
160.0	4.03	2.47	1.43	0.494	0.303	0.175
165.0	4.82	2.69	1.62	0.590	0.330	0.199
170.0	4.77	2.56	1.82	0.585	0.313	0.223
175.0	4.86	2.48	2.03	0.596	0.303	0.249
180.0	4.67	2.27	2.04	0.573	0.278	0.250
185.0	3.93	2.18	2.06	0.482	0.267	0.252
195.0	1.75	0.95	0.09	0.215	0.116	0.012

Table A1-26 - Velocity profile data

Swirl setting - 4.5 high total air flow rate

Primary air temperature - 41.8°C

Secondary air temperature - 41.8°C

Axial location of traverse: exit quarl (x = 0.42 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
-75.0	-7.08	6.96	2.48	-0.188	0.185	0.066
-50.0	-8.44	5.11	2.16	-0.224	0.136	0.057
-25.0	-9.87	2.79	1.05	-0.262	0.074	0.028
0.0	-10.56	0.09	0.31	-0.280	0.002	0.008
5.0	-10.70	0.71	0.52	-0.284	0.019	0.014
10.0	-10.25	1.53	0.81	-0.272	0.041	0.022
15.0	-10.21	1.95	1.15	-0.271	0.052	0.030
20.0	-10.40	2.56	1.49	-0.276	0.068	0.040
25.0	-10.53	3.18	1.61	-0.279	0.084	0.043
30.0	-10.19	3.71	1.87	-0.270	0.098	0.050
35.0	-9.82	4.39	1.90	-0.261	0.117	0.050
40.0	-9.56	5.04	2.17	-0.254	0.134	0.058
45.0	-9.56	5.63	2.25	-0.254	0.149	0.060
50.0	-9.18	6.21	2.29	-0.244	0.165	0.061
55.0	-8.92	6.73	2.33	-0.237	0.179	0.062
60.0	-8.87	7.24	2.39	-0.235	0.192	0.064
65.0	-8.40	7.84	2.41	-0.223	0.208	0.064
70.0	-8.50	8.07	2.45	-0.226	0.214	0.065
75.0	-8.10	8.35	2.41	-0.215	0.222	0.064
80.0	-7.61	8.66	2.44	-0.202	0.230	0.065
85.0	-7.39	8.65	2.51	-0.196	0.230	0.067
90.0	-7.22	8.85	2.55	-0.192	0.235	0.068
95.0	-6.48	8.92	2.58	-0.172	0.237	0.068
100.0	-5.74	8.68	2.66	-0.152	0.230	0.071
105.0	-4.79	8.58	2.63	-0.127	0.228	0.070
110.0	-3.84	8.24	2.61	-0.102	0.219	0.069

Table A1-26 (cont'd)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
115.0	-2.65	7.65	2.58	-0.070	0.203	0.068
120.0	-1.18	7.05	2.71	-0.031	0.187	0.072
125.0	0.00	6.43	2.79	0.000	0.171	0.074
130.0	1.53	6.05	2.84	0.041	0.161	0.076
135.0	3.48	6.99	2.65	0.092	0.186	0.070
140.0	6.33	8.58	3.15	0.168	0.228	0.084
145.0	9.13	9.33	3.72	0.242	0.248	0.099
150.0	12.33	10.27	4.66	0.327	0.273	0.124
155.0	15.56	10.62	5.62	0.413	0.282	0.149
160.0	18.03	10.92	7.19	0.478	0.290	0.191
165.0	20.57	11.50	8.44	0.546	0.305	0.224
170.0	22.21	11.22	9.11	0.590	0.298	0.242
175.0	22.57	11.10	9.83	0.599	0.295	0.261
180.0	21.39	10.43	10.77	0.568	0.277	0.286
185.0	19.27	9.48	10.05	0.511	0.252	0.267
190.0	13.89	7.14	9.41	0.369	0.190	0.250

Table A1-27 - Velocity profile data

Swirl setting - 4.5 low total air flow rate

Primary air temperature - 32.5°C

Secondary air temperature - 32.5°C

Axial location of traverse: exit quarl (x = 0.42 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
-75.0	-2.12	1.32	0.33	-0.263	0.164	0.041
-50.0	-2.34	1.09	0.16	-0.290	0.135	0.019
-25.0	-2.69	0.43	-0.06	-0.334	0.053	-0.008
0.0	-2.46	0.35	0.22	-0.306	0.043	0.027
5.0	-2.40	0.44	0.28	-0.298	0.055	0.035
10.0	-2.61	0.58	0.35	-0.324	0.072	0.043
15.0	-2.44	0.72	0.48	-0.302	0.089	0.059
20.0	-2.24	0.81	0.42	-0.278	0.101	0.052
25.0	-2.37	0.93	0.43	-0.294	0.116	0.054
30.0	-2.33	1.11	0.48	-0.289	0.138	0.060
35.0	-2.27	1.21	0.50	-0.282	0.150	0.062
40.0	-2.15	1.26	0.52	-0.266	0.156	0.065
45.0	-2.10	1.47	0.55	-0.261	0.183	0.066
50.0	-2.12	1.49	0.66	-0.262	0.184	0.082
55.0	-1.92	1.61	0.64	-0.238	0.200	0.079
60.0	-1.94	1.72	0.61	-0.241	0.213	0.076
65.0	-1.99	1.90	0.64	-0.246	0.235	0.079
70.0	-2.07	2.06	0.70	-0.257	0.255	0.086
75.0	-1.81	1.96	0.66	-0.225	0.243	0.081
80.0	-1.66	1.98	0.66	-0.206	0.246	0.082
85.0	-1.58	1.99	0.65	-0.197	0.247	0.081
90.0	-1.40	1.94	0.75	-0.174	0.241	0.093
95.0	-1.22	1.86	0.72	-0.151	0.231	0.089
100.0	-1.17	1.95	0.69	-0.146	0.242	0.086
105.0	-1.02	1.78	0.65	-0.126	0.221	0.081
110.0	-0.86	1.75	0.66	-0.107	0.217	0.082

Table A1-27 (cont'd)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
115.0	-0.44	1.50	0.77	-0.054	0.186	0.096
120.0	-0.28	1.40	0.97	-0.034	0.174	0.120
125.0	0.05	1.71	0.69	0.006	0.213	0.085
130.0	0.37	1.55	0.67	0.046	0.192	0.083
135.0	0.71	1.42	0.71	0.088	0.176	0.088
140.0	1.42	1.90	0.85	0.176	0.236	0.105
145.0	1.97	2.15	0.85	0.245	0.267	0.105
150.0	2.66	2.30	1.03	0.330	0.285	0.127
155.0	3.36	2.36	0.96	0.417	0.292	0.119
160.0	3.90	2.46	1.35	0.484	0.305	0.168
165.0	4.47	2.53	1.71	0.555	0.314	0.212
170.0	4.81	2.56	1.80	0.597	0.317	0.223
175.0	4.88	2.40	2.11	0.605	0.298	0.262
180.0	4.72	2.38	2.11	0.585	0.296	0.262
185.0	4.02	2.18	2.21	0.499	0.271	0.274
190.0	2.80	1.58	2.10	0.347	0.197	0.260

Table A1-28 - Velocity profile data

Swirl setting - 0.0

Primary air temperature - 37.0°C

Secondary air temperature - 37.0°C

Axial location of traverse: first tunnel port (x = 0.79 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	24.83	0.00	2.08	0.675	0.000	0.057
20.0	25.85	0.00	2.30	0.703	0.000	0.063
40.0	24.48	0.00	2.52	0.666	0.000	0.069
60.0	20.09	0.00	2.82	0.546	0.000	0.077
80.0	14.60	0.51	2.91	0.397	0.014	0.079
100.0	10.75	0.19	3.52	0.292	0.005	0.096
120.0	9.81	0.00	3.25	0.267	0.000	0.088
140.0	8.03	0.00	2.10	0.218	0.000	0.057
160.0	6.89	1.15	3.21	0.187	0.031	0.087
180.0	5.13	0.00	2.63	0.139	0.000	0.072
200.0	3.47	0.00	2.62	0.094	0.000	0.071
220.0	0.00	0.00	0.00	0.000	0.000	0.000
260.0	0.00	0.00	0.00	0.000	0.000	0.000
280.0	0.00	0.00	0.00	0.000	0.000	0.000
300.0	0.00	0.00	0.00	0.000	0.000	0.000
320.0	0.00	0.00	0.00	0.000	0.000	0.000
340.0	0.00	0.00	0.00	0.000	0.000	0.000
360.0	0.00	0.00	0.00	0.000	0.000	0.000
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-29 - Velocity profile data

Swirl setting - 0.0

Primary air temperature - 42.5°C

Secondary air temperature - 42.5°C

Axial location of traverse: second tunnel port ($x = 1.07$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	13.90	0.00	1.05	0.368	0.000	0.028
20.0	16.04	0.00	1.43	0.425	0.000	0.038
40.0	16.55	0.00	2.80	0.439	0.000	0.074
60.0	16.79	0.59	3.25	0.445	0.016	0.086
80.0	18.83	0.72	3.73	0.499	0.019	0.099
100.0	15.98	0.75	3.67	0.424	0.020	0.097
120.0	15.45	0.70	3.59	0.410	0.019	0.095
140.0	12.82	0.56	3.45	0.340	0.015	0.091
160.0	10.92	0.19	2.59	0.290	0.005	0.069
180.0	8.34	0.17	3.51	0.213	0.004	0.093
200.0	7.29	0.06	2.99	0.193	0.002	0.079
220.0	5.72	0.50	3.54	0.152	0.013	0.094
240.0	4.49	0.00	2.51	0.119	0.000	0.067
260.0	4.76	0.00	2.72	0.126	0.000	0.072
280.0	0.00	0.00	0.00	0.000	0.000	0.000
300.0	4.75	0.00	2.27	0.126	0.000	0.060
320.0	3.05	0.00	2.20	0.080	0.000	0.058
340.0	3.18	0.00	1.61	0.084	0.000	0.043
360.0	1.97	0.00	1.23	0.052	0.000	0.033
380.0	0.00	0.00	0.00	0.000	0.000	0.000
400.0	0.00	0.00	0.00	0.000	0.000	0.000
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-30 - Velocity profile data

Swirl setting - 0.0

Primary air temperature - 42.8°C

Secondary air temperature - 42.8°C

Axial location of traverse: third tunnel port ($x = 1.37$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	5.91	0.96	-0.43	0.158	0.026	-0.011
20.0	7.13	0.69	0.28	0.191	0.018	0.008
40.0	7.93	0.48	0.60	0.212	0.013	0.016
60.0	9.17	0.08	1.55	0.245	0.002	0.041
80.0	9.26	0.65	2.18	0.247	0.017	0.058
100.0	10.08	0.35	2.08	0.269	0.009	0.056
120.0	8.31	0.15	2.16	0.222	0.004	0.058
140.0	9.90	0.26	2.42	0.265	0.007	0.065
160.0	10.98	0.29	2.69	0.293	0.008	0.072
180.0	9.06	0.00	2.11	0.242	0.000	0.056
220.0	3.84	0.03	1.78	0.103	0.001	0.048
240.0	8.06	0.14	2.41	0.215	0.004	0.064
260.0	5.67	0.10	2.00	0.151	0.003	0.053
280.0	3.53	0.31	1.32	0.094	0.008	0.035
300.0	5.33	0.34	1.51	0.142	0.009	0.040
340.0	2.27	0.38	1.24	0.061	0.010	0.033
360.0	2.29	0.44	0.82	0.061	0.012	0.022
380.0	0.00	0.00	0.00	0.000	0.000	0.000
400.0	3.09	0.98	1.01	0.083	0.026	0.027
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-31 - Velocity profile data

Swirl setting - 0.5

Primary air temperature - 38.3°C

Secondary air temperature - 38.3°C

Axial location of traverse: first tunnel port (x = 0.79 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	20.50	1.25	2.80	0.555	0.034	0.076
20.0	22.20	0.97	3.92	0.601	0.026	0.106
40.0	22.29	0.19	4.98	0.603	0.005	0.135
60.0	21.28	0.19	5.40	0.576	0.005	0.146
80.0	18.64	0.65	5.66	0.504	0.018	0.153
100.0	15.85	1.25	5.78	0.429	0.034	0.156
120.0	12.97	1.82	5.72	0.351	0.049	0.155
140.0	10.40	2.53	5.65	0.281	0.069	0.153
160.0	8.05	2.76	5.93	0.218	0.075	0.160
340.0	0.41	2.32	1.62	0.011	0.063	0.044
360.0	0.55	2.49	0.92	0.015	0.067	0.025
380.0	0.33	2.50	0.66	0.009	0.068	0.018
400.0	0.42	1.87	0.38	0.011	0.051	0.010
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-32 - Velocity profile data

Swirl setting - 0.5

Primary air temperature - 41.5°C

Secondary air temperature - 41.5°C

Axial location of traverse: second tunnel port ($x = 1.07$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	10.16	0.53	1.86	0.270	0.014	0.049
20.0	11.57	0.61	2.28	0.307	0.016	0.061
40.0	12.86	0.34	2.79	0.342	0.009	0.074
60.0	13.39	0.00	3.39	0.356	0.000	0.090
80.0	14.07	0.00	3.77	0.374	0.000	0.100
100.0	14.25	0.00	3.87	0.379	0.000	0.103
120.0	13.10	0.00	4.26	0.348	0.000	0.113
140.0	12.74	0.71	4.38	0.338	0.019	0.116
160.0	11.25	0.39	4.32	0.299	0.010	0.115
180.0	9.62	0.71	4.10	0.256	0.019	0.109
200.0	8.70	0.56	4.14	0.231	0.015	0.110
220.0	7.25	0.89	3.98	0.193	0.024	0.106
240.0	6.32	1.00	3.84	0.168	0.027	0.102
260.0	5.43	1.01	3.42	0.144	0.027	0.091
280.0	4.83	1.12	3.33	0.128	0.030	0.088
300.0	3.26	0.66	2.64	0.087	0.018	0.070
320.0	3.64	0.72	2.71	0.097	0.019	0.072
340.0	2.69	0.32	1.81	0.072	0.009	0.048
360.0	2.24	0.12	1.81	0.060	0.003	0.048
380.0	2.83	0.30	1.33	0.075	0.008	0.035
400.0	2.48	0.46	0.78	0.066	0.012	0.021
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-33 - Velocity profile data

Swirl setting - 0.5

Primary air temperature - 42.5°C

Secondary air temperature - 42.5°C

Axial location of traverse: third tunnel port (x = 1.37 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	3.09	0.24	0.28	0.082	0.006	0.007
20.0	3.99	0.41	0.71	0.106	0.011	0.019
40.0	5.23	0.41	0.97	0.139	0.011	0.020
60.0	5.80	0.50	1.26	0.154	0.013	0.035
80.0	6.64	0.29	1.54	0.177	0.008	0.041
100.0	6.94	0.12	2.47	0.185	0.003	0.066
120.0	7.50	0.13	2.12	0.200	0.003	0.056
140.0	8.30	0.00	2.46	0.221	0.000	0.065
160.0	8.31	0.00	2.54	0.221	0.000	0.068
180.0	8.56	0.07	2.71	0.228	0.002	0.072
200.0	8.11	0.14	2.70	0.216	0.004	0.072
220.0	7.61	0.13	2.81	0.202	0.004	0.075
240.0	7.77	0.14	2.74	0.207	0.004	0.073
260.0	7.79	0.00	2.74	0.207	0.000	0.073
280.0	6.77	0.00	2.67	0.180	0.000	0.071
300.0	6.47	0.00	2.58	0.172	0.000	0.069
320.0	5.64	0.13	2.10	0.150	0.003	0.056
340.0	5.46	0.10	1.97	0.145	0.003	0.052
360.0	4.82	0.27	1.73	0.128	0.007	0.046
380.0	4.99	0.52	1.65	0.133	0.014	0.044
400.0	5.10	0.67	1.67	0.136	0.018	0.044
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-34 - Velocity profile data

Swirl setting - 1.0

Primary air temperature - 38.1°C

Secondary air temperature - 38.1°C

Axial location of traverse: first tunnel port (x = 0.79 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	5.55	0.19	1.87	0.151	0.005	0.051
20.0	6.39	0.28	2.01	0.173	0.008	0.055
40.0	6.81	0.66	3.24	0.185	0.018	0.088
60.0	6.80	0.49	3.47	0.184	0.013	0.094
80.0	6.89	0.78	4.20	0.187	0.021	0.114
100.0	6.36	0.78	4.51	0.172	0.021	0.122
300.0	0.63	1.85	0.45	0.017	0.050	0.012
320.0	0.52	1.87	0.17	0.014	0.051	0.005
340.0	0.39	1.92	0.67	0.011	0.052	0.018
360.0	0.18	1.73	0.39	0.005	0.047	0.011
380.0	0.27	1.52	0.88	0.007	0.041	0.024
400.0	0.29	1.47	1.01	0.008	0.040	0.027
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-35 - Velocity profile data

Swirl setting - 2.0

Primary air temperature - 38.1°C

Secondary air temperature - 38.1°C

Axial location of traverse: first tunnel port (x = 0.79 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	-2.21	1.18	-0.02	-0.060	0.032	-0.001
20.0	-1.80	1.49	0.03	-0.049	0.040	0.001
40.0	-0.69	1.26	-0.74	-0.019	0.034	-0.020
60.0	0.00	1.88	-1.39	0.000	0.051	-0.038
80.0	1.19	3.27	-1.34	0.032	0.088	-0.036
100.0	2.46	4.18	-0.97	0.067	0.113	-0.026
120.0	3.82	4.55	-0.60	0.104	0.123	-0.016
140.0	4.57	4.49	-0.26	0.124	0.122	-0.007
160.0	4.89	4.10	0.24	0.133	0.111	0.007
180.0	4.73	3.56	0.53	0.128	0.097	0.014
200.0	4.13	2.84	0.78	0.112	0.077	0.021
220.0	3.28	2.24	0.91	0.089	0.061	0.025
240.0	2.12	1.62	0.75	0.057	0.044	0.020
260.0	1.16	1.07	0.55	0.031	0.029	0.015
280.0	0.55	0.69	-0.14	0.015	0.019	-0.004
340.0	-1.02	1.69	-0.31	-0.028	0.046	-0.008
360.0	-1.41	2.25	-0.60	-0.038	0.061	-0.016
380.0	-1.69	2.43	-0.01	-0.046	0.066	-0.000
400.0	-1.47	2.23	0.24	-0.040	0.060	0.006
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-36 - Velocity profile data

Swirl setting - 2.0

Primary air temperature - 45.3°C

Secondary air temperature - 45.3°C

Axial location of traverse: second tunnel port ($x = 1.07$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	0.34	0.00	0.00	0.009	0.000	0.000
180.0	0.34	1.24	-0.82	0.009	0.033	-0.022
200.0	0.54	1.77	-0.41	0.015	0.048	-0.011
220.0	0.70	1.78	-0.25	0.019	0.048	-0.007
240.0	0.61	1.71	-0.20	0.016	0.046	-0.005
260.0	0.88	1.93	0.19	0.024	0.052	0.005
280.0	0.70	1.78	0.17	0.019	0.048	0.005
300.0	0.53	2.11	0.19	0.014	0.057	0.005
320.0	0.78	2.50	0.23	0.021	0.067	0.006
340.0	0.67	2.70	0.09	0.018	0.072	0.003
360.0	0.65	2.62	0.24	0.017	0.070	0.006
380.0	0.59	2.79	0.25	0.016	0.075	0.007
400.0	0.74	2.43	0.53	0.020	0.065	0.014
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-37 - Velocity profile data

Swirl setting - 2.0

Primary air temperature - 44.0°C

Secondary air temperature - 44.0°C

Axial location of traverse: third tunnel port (x = 1.37 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	-1.03	0.00	0.00	-0.027	0.000	0.000
100.0	-1.03	0.65	0.99	-0.027	0.017	0.026
120.0	-0.62	0.75	0.72	-0.016	0.020	0.019
140.0	-1.02	1.12	0.62	-0.027	0.029	0.016
160.0	-1.19	1.76	0.54	-0.031	0.046	0.014
180.0	-0.91	1.99	0.71	-0.024	0.052	0.019
200.0	-0.39	1.49	0.52	-0.010	0.039	0.014
220.0	-0.23	1.90	0.54	-0.006	0.050	0.014
240.0	-0.08	2.41	0.53	-0.002	0.064	0.014
260.0	0.14	2.69	0.37	0.004	0.071	0.010
280.0	0.74	3.19	0.29	0.020	0.084	0.008
300.0	1.00	3.16	0.35	0.026	0.083	0.009
320.0	1.34	3.48	0.45	0.035	0.092	0.012
340.0	1.64	3.72	0.36	0.043	0.098	0.010
360.0	1.93	4.19	0.69	0.051	0.111	0.018
380.0	2.41	4.17	0.85	0.064	0.110	0.022
400.0	2.26	3.83	1.21	0.060	0.101	0.032
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-38 - Velocity profile data

Swirl setting - 3.0

Primary air temperature - 34.9°C

Secondary air temperature - 34.9°C

Axial location of traverse: first tunnel port ($x = 0.79$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	-4.40	2.84	-1.43	-0.120	0.078	-0.039
20.0	-3.32	3.44	-2.12	-0.091	0.094	-0.058
40.0	-2.00	3.81	-2.27	-0.055	0.104	-0.062
60.0	-0.56	4.26	-2.85	-0.015	0.116	-0.078
80.0	0.42	4.40	-3.23	0.012	0.120	-0.088
100.0	1.70	5.09	-3.26	0.047	0.139	-0.089
120.0	3.96	5.66	-2.44	0.108	0.155	-0.067
140.0	5.15	5.62	-2.03	0.141	0.154	-0.056
160.0	6.14	5.17	-1.49	0.168	0.141	-0.041
180.0	6.81	5.00	-0.57	0.186	0.137	-0.016
200.0	6.27	4.23	-0.15	0.171	0.116	-0.004
220.0	5.24	3.47	0.49	0.143	0.095	0.014
240.0	4.24	3.14	1.11	0.116	0.086	0.030
260.0	2.35	2.10	0.76	0.064	0.057	0.021
280.0	0.80	1.36	0.14	0.022	0.037	0.004
300.0	-0.06	1.58	-0.54	-0.002	0.043	-0.015
320.0	-0.63	2.17	-0.31	-0.017	0.059	-0.009
340.0	-1.39	2.67	-0.58	-0.038	0.073	-0.016
360.0	-2.03	3.06	-0.59	-0.055	0.084	-0.016
380.0	-2.35	3.46	-0.25	-0.064	0.095	-0.007
400.0	-1.92	2.93	0.31	-0.052	0.080	0.009
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-39 - Velocity profile data

Swirl setting - 3.0

Primary air temperature - 35.3°C

Secondary air temperature - 35.3°C

Axial location of traverse: second tunnel port (x = 1.07 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	0.00	0.00	0.00	0.000	0.000	0.000
20.0	0.00	0.00	0.00	0.000	0.000	0.000
80.0	-1.65	1.61	-1.36	-0.045	0.044	-0.037
100.0	-1.49	2.30	-1.27	-0.041	0.063	-0.035
120.0	-1.30	2.44	-1.13	-0.035	0.067	-0.031
140.0	-1.16	2.71	-0.88	-0.032	0.074	-0.024
160.0	-1.01	2.91	-0.39	-0.027	0.079	-0.011
180.0	-0.52	2.63	-0.29	-0.014	0.072	-0.008
200.0	-0.41	2.89	-0.23	-0.011	0.079	-0.006
220.0	0.15	2.53	-0.06	0.004	0.069	-0.002
240.0	0.26	2.98	0.18	0.007	0.081	0.005
260.0	0.53	3.37	0.30	0.015	0.092	0.008
280.0	0.78	3.26	0.57	0.021	0.089	0.015
300.0	0.87	3.48	0.62	0.024	0.095	0.017
320.0	1.07	3.61	0.62	0.029	0.098	0.017
340.0	1.32	3.72	0.68	0.036	0.101	0.019
360.0	1.64	3.60	0.56	0.045	0.098	0.015
380.0	1.83	3.85	0.61	0.050	0.105	0.017
400.0	1.84	3.85	0.91	0.050	0.105	0.025
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-40 - Velocity profile data

Swirl setting - 3.0

Primary air temperature - 44.0°C

Secondary air temperature - 44.0°C

Axial location of traverse: third tunnel port ($x = 1.37$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	-0.42	1.77	1.20	-0.011	0.047	0.032
20.0	-0.68	1.51	1.30	-0.018	0.040	0.035
100.0	-1.58	2.34	0.90	-0.042	0.062	0.024
120.0	-1.57	2.89	0.75	-0.042	0.077	0.020
140.0	-1.46	3.16	0.75	-0.039	0.084	0.020
160.0	-1.23	2.97	0.55	-0.033	0.079	0.015
180.0	-1.04	2.84	0.44	-0.027	0.076	0.012
200.0	-0.74	2.99	0.27	-0.020	0.079	0.007
220.0	-0.69	3.21	0.29	-0.018	0.085	0.008
240.0	-0.38	3.57	0.32	-0.010	0.095	0.009
260.0	0.00	3.77	0.34	0.000	0.100	0.009
280.0	0.35	3.95	0.35	0.009	0.105	0.009
300.0	1.11	3.69	0.17	0.030	0.098	0.004
320.0	1.39	4.27	0.53	0.037	0.113	0.014
340.0	1.78	4.89	0.46	0.047	0.130	0.012
360.0	2.03	4.91	0.67	0.054	0.130	0.018
380.0	2.49	4.49	0.92	0.066	0.119	0.024
400.0	2.54	4.40	1.30	0.068	0.117	0.035
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-41 - Velocity profile data

Swirl setting - 4.0

Primary air temperature - 44.9°C

Secondary air temperature - 44.9°C

Axial location of traverse: first tunnel port (x = 0.79 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	-6.60	3.66	-2.58	-0.174	0.096	-0.068
20.0	-6.11	4.44	-3.15	-0.161	0.117	-0.083
40.0	-4.86	5.03	-3.51	-0.128	0.132	-0.092
60.0	-3.47	4.69	-4.40	-0.091	0.123	-0.116
140.0	3.06	5.88	-4.30	0.081	0.155	-0.113
160.0	5.03	6.22	-3.25	0.133	0.164	-0.086
180.0	6.49	6.46	-2.00	0.171	0.170	-0.053
200.0	7.58	5.82	-0.58	0.200	0.153	-0.015
220.0	6.92	5.01	0.69	0.182	0.132	0.018
240.0	5.74	4.09	0.63	0.151	0.108	0.017
260.0	4.35	3.46	1.30	0.115	0.091	0.034
280.0	2.62	2.58	1.38	0.069	0.068	0.036
300.0	1.09	2.29	0.23	0.029	0.060	0.006
320.0	0.12	3.31	-0.32	0.003	0.087	-0.008
340.0	-1.54	3.39	-0.62	-0.041	0.089	-0.016
360.0	-2.64	4.14	-0.77	-0.069	0.109	-0.020
380.0	-2.96	4.93	-0.49	-0.078	0.130	-0.013
400.0	-2.48	3.82	-0.40	-0.065	0.101	-0.011
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-42 - Velocity profile data

Swirl setting - 4.0

Primary air temperature - 41.2°C

Secondary air temperature - 41.2°C

Axial location of traverse: second tunnel port (x = 1.07 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	-1.90	0.88	-0.66	-0.051	0.024	-0.018
20.0	0.00	0.00	0.00	0.000	0.000	0.000
40.0	-3.66	2.57	0.21	-0.098	0.069	0.006
60.0	-3.53	3.85	-0.17	-0.095	0.103	-0.005
80.0	-2.94	4.67	-0.18	-0.079	0.125	-0.005
100.0	-2.41	4.73	-0.56	-0.065	0.127	-0.015
120.0	-2.24	4.88	-0.29	-0.060	0.131	-0.008
140.0	-1.98	4.77	-0.18	-0.053	0.128	-0.005
160.0	-1.47	4.51	-0.27	-0.039	0.121	-0.007
180.0	-1.20	4.81	-0.03	-0.032	0.129	-0.001
200.0	-0.67	4.49	-0.11	-0.018	0.120	-0.003
220.0	-0.19	4.41	0.01	-0.005	0.118	0.000
240.0	0.21	4.34	0.00	0.006	0.116	0.000
260.0	0.70	4.32	0.20	0.019	0.116	0.005
280.0	1.11	4.31	0.32	0.030	0.115	0.009
300.0	1.52	4.40	0.29	0.041	0.118	0.008
320.0	1.81	4.71	0.42	0.049	0.126	0.011
340.0	2.40	4.61	0.46	0.064	0.123	0.012
360.0	2.91	4.59	0.48	0.078	0.123	0.013
380.0	3.34	4.36	0.70	0.090	0.117	0.019
400.0	3.55	4.23	0.96	0.095	0.113	0.026
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-43 - Velocity profile data

Swirl setting - 4.0

Primary air temperature - 42.7°C

Secondary air temperature - 42.7°C

Axial location of traverse: third tunnel port (x = 1.37 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	-0.76	4.09	1.63	-0.020	0.108	0.043
20.0	-0.25	3.52	1.40	-0.007	0.093	0.037
40.0	0.00	0.00	0.00	0.000	0.000	0.000
60.0	-1.50	3.01	1.42	-0.040	0.080	0.038
80.0	-1.63	4.19	1.25	-0.043	0.111	0.033
100.0	-1.55	4.63	1.06	-0.041	0.122	0.028
120.0	-1.39	4.34	0.99	-0.037	0.115	0.026
140.0	-1.49	4.60	0.65	-0.040	0.122	0.017
160.0	-1.37	4.49	0.42	-0.036	0.119	0.011
180.0	-1.11	4.15	0.38	-0.029	0.110	0.010
200.0	-0.81	4.16	0.42	-0.021	0.110	0.011
220.0	-0.25	4.03	0.19	-0.007	0.107	0.005
240.0	0.33	4.46	0.21	0.009	0.118	0.006
260.0	0.83	4.67	0.17	0.022	0.124	0.005
280.0	1.07	4.96	0.31	0.028	0.131	0.008
300.0	1.54	5.18	0.32	0.041	0.137	0.009
320.0	2.21	5.25	0.36	0.058	0.139	0.009
340.0	2.70	5.19	0.52	0.072	0.137	0.014
360.0	2.97	5.36	0.69	0.079	0.142	0.018
380.0	3.24	4.89	1.10	0.086	0.129	0.029
400.0	3.38	4.82	1.26	0.089	0.128	0.033
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-44 - Velocity profile data

Swirl setting - 4.5

Primary air temperature - 42.2°C

Secondary air temperature - 42.2°C

Axial location of traverse: first tunnel port ($x = 0.79$ m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	-6.80	3.39	-2.89	-0.181	0.090	-0.077
20.0	-6.56	4.83	-3.23	-0.174	0.128	-0.086
40.0	-5.77	5.59	-3.41	-0.153	0.149	-0.091
60.0	-4.66	5.96	-3.85	-0.124	0.159	-0.102
80.0	-2.01	5.67	-4.92	-0.053	0.151	-0.131
140.0	2.74	5.49	-4.96	0.073	0.146	-0.132
160.0	5.47	6.52	-3.32	0.145	0.173	-0.088
180.0	6.83	6.60	-2.22	0.182	0.175	-0.059
200.0	7.21	5.33	-1.17	0.192	0.142	-0.031
220.0	7.92	5.55	0.34	0.211	0.147	0.009
240.0	6.07	4.33	0.83	0.161	0.115	0.022
260.0	4.70	3.60	1.49	0.125	0.096	0.040
280.0	2.49	2.77	1.76	0.066	0.073	0.047
320.0	0.13	2.46	0.65	0.003	0.065	0.017
340.0	-1.34	3.90	0.06	-0.036	0.104	0.002
360.0	-2.37	4.37	-0.22	-0.063	0.116	-0.006
380.0	-2.98	5.16	-0.32	-0.079	0.137	-0.008
400.0	-2.63	5.16	0.52	-0.070	0.137	0.014
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-45 - Velocity profile data

Swirl setting - 4.5

Primary air temperature - 44.0°C

Secondary air temperature - 44.0°C

Axial location of traverse: second tunnel port (x = 1.07 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	-2.16	1.38	-0.52	-0.057	0.036	-0.014
20.0	0.00	0.00	0.00	0.000	0.000	0.000
40.0	-3.29	2.53	-1.06	-0.087	0.067	-0.028
60.0	-2.86	3.79	-0.87	-0.075	0.100	-0.023
80.0	-2.68	4.46	-0.43	-0.071	0.118	-0.011
100.0	-2.75	5.17	-0.43	-0.072	0.136	-0.011
120.0	-2.25	5.08	-0.50	-0.059	0.134	-0.013
140.0	-1.94	4.94	-0.31	-0.051	0.130	-0.008
160.0	-1.38	4.86	-0.44	-0.036	0.128	-0.012
180.0	-1.03	4.83	-0.38	-0.027	0.127	-0.010
200.0	-0.48	4.45	-0.07	-0.013	0.117	-0.002
220.0	-0.17	4.87	-0.12	-0.004	0.129	-0.003
240.0	0.31	3.96	-0.35	0.008	0.104	-0.009
260.0	0.93	4.78	0.04	0.025	0.126	0.001
280.0	1.34	4.72	0.26	0.035	0.124	0.007
300.0	1.73	4.79	0.29	0.046	0.126	0.008
320.0	1.97	4.46	0.53	0.052	0.118	0.014
340.0	2.62	4.67	0.48	0.069	0.123	0.013
360.0	3.12	4.80	0.73	0.082	0.127	0.019
380.0	3.69	4.89	0.73	0.097	0.129	0.019
400.0	3.77	4.34	1.30	0.099	0.114	0.034
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-46 - Velocity profile data

Swirl setting - 4.5

Primary air temperature - 38.2°C

Secondary air temperature - 38.2°C

Axial location of traverse: third tunnel port (x = 1.37 m)

R (mm)	U (m/s)	W (m/s)	V (m/s)	U/VREF	W/VREF	V/VREF
0.0	-1.10	3.71	1.87	-0.030	0.100	0.050
20.0	-0.75	2.90	1.77	-0.020	0.078	0.048
60.0	-1.88	3.47	1.41	-0.051	0.094	0.038
80.0	-2.07	4.54	1.20	-0.056	0.123	0.032
100.0	-2.06	4.85	1.05	-0.056	0.131	0.028
120.0	-1.71	4.82	0.72	-0.046	0.130	0.019
140.0	-1.62	4.56	0.69	-0.044	0.123	0.019
160.0	-1.41	4.75	0.44	-0.038	0.128	0.012
180.0	-1.07	4.47	0.34	-0.029	0.121	0.009
200.0	-0.70	4.21	0.20	-0.019	0.114	0.005
220.0	-0.36	4.54	0.16	-0.010	0.122	0.004
240.0	0.25	4.69	0.17	0.007	0.126	0.005
260.0	0.92	4.69	0.15	0.025	0.127	0.004
280.0	1.22	5.10	0.21	0.033	0.138	0.006
300.0	1.73	5.28	0.21	0.047	0.143	0.006
320.0	2.19	5.43	0.26	0.059	0.146	0.007
340.0	2.76	5.25	0.33	0.074	0.142	0.009
360.0	3.01	5.31	0.41	0.081	0.143	0.011
380.0	3.30	5.11	0.73	0.089	0.138	0.020
400.0	2.93	4.38	1.02	0.079	0.118	0.028
414.3	0.00	0.00	0.00	0.000	0.000	0.000

Table A1-47 - Reference velocities

Measurement location (distance m)	Primary, secondary air (kg/s)	Swirl setting	Reference velocity (m/s)
Swirl generator exit (0.0 m)	0.0457, 0.1235	0.0	9.17
		0.5	8.77
		1.0	8.92
		2.0	8.91
		3.0	8.27
		4.0	8.80
		4.5	9.06
	0.2055, 0.5557	0.0	38.49
		0.5	37.70
		1.0	37.11
		2.0	37.62
		3.0	39.02
		4.0	41.27
		4.5	39.86
Quarl exit (0.38 m)	0.0457, 0.1235	0.0	8.57
		0.5	8.05
		1.0	*
		2.0	8.16
		3.0	8.17
		4.0	8.16
		4.5	8.06
	0.2055, 0.5557	0.0	36.59
		0.5	36.72
		1.0	37.04
		2.0	37.53
		3.0	37.13
		4.0	37.57
		4.5	37.67

Table A1-47 (cont'd)

Measurement location (distance m)	Primary, secondary air (kg/s)	Swirl setting	Reference velocity (m/s)
Tunnel first port (0.79 m)	0.2055, 0.5557	0.0	36.78
		0.5	36.96
		1.0	36.87
		2.0	36.90
		3.0	36.57
		4.0	37.98
		4.5	37.62
Tunnel second port (1.07 m)	0.2055, 0.5557	0.0	37.71
		0.5	37.64
		1.0	*
		2.0	37.23
		3.0	36.72
		4.0	37.30
		4.5	37.91
Tunnel third port (1.37 m)	0.2055, 0.5557	0.0	37.44
		0.5	37.60
		1.0	*
		2.0	37.89
		3.0	37.65
		4.0	37.82
		4.5	37.08

*Data in error, see Appendix 4.

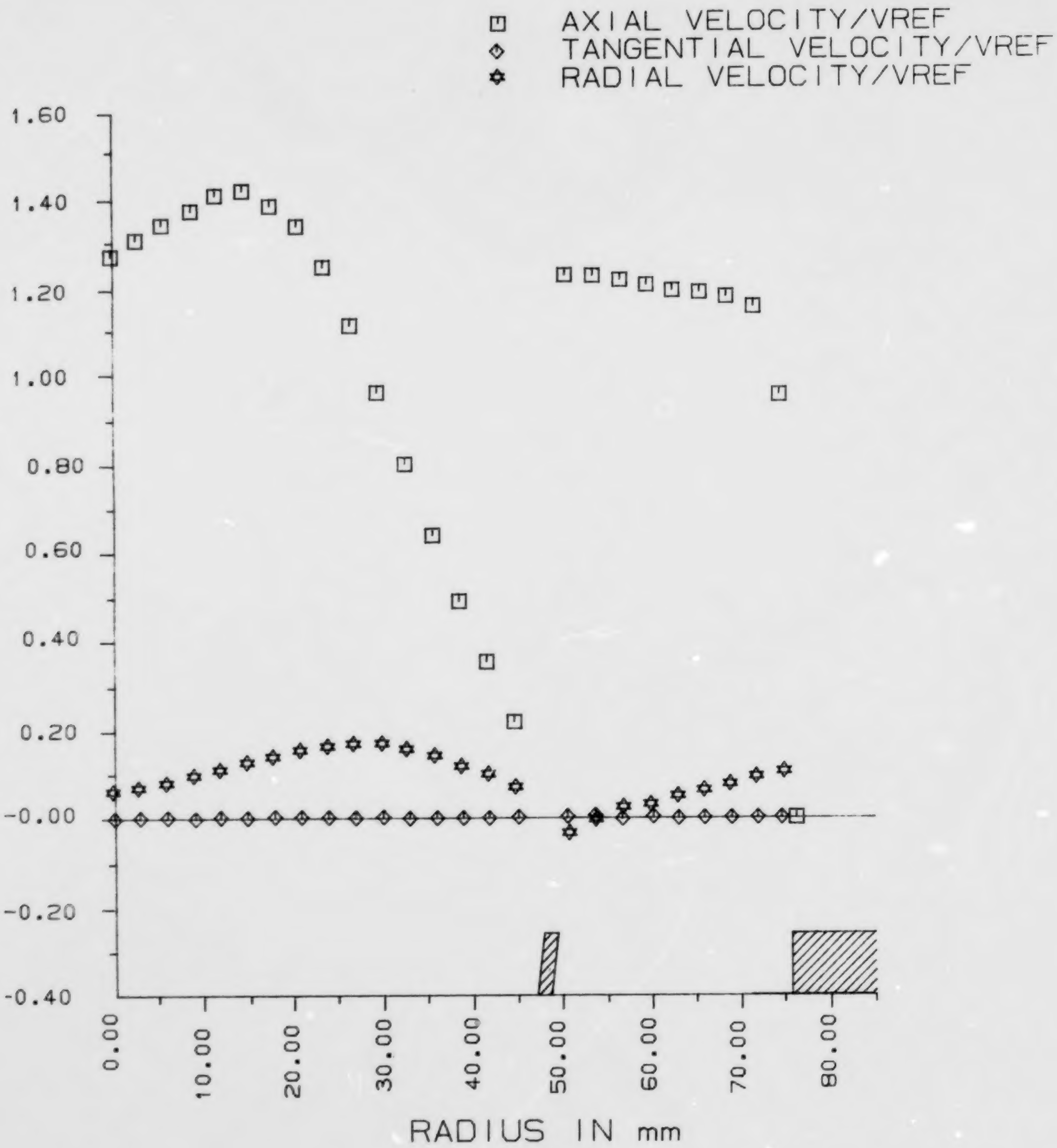


Fig. A1-1 - Velocity profiles at the swirl generator exit (high flow rate, swirl setting 0.0)

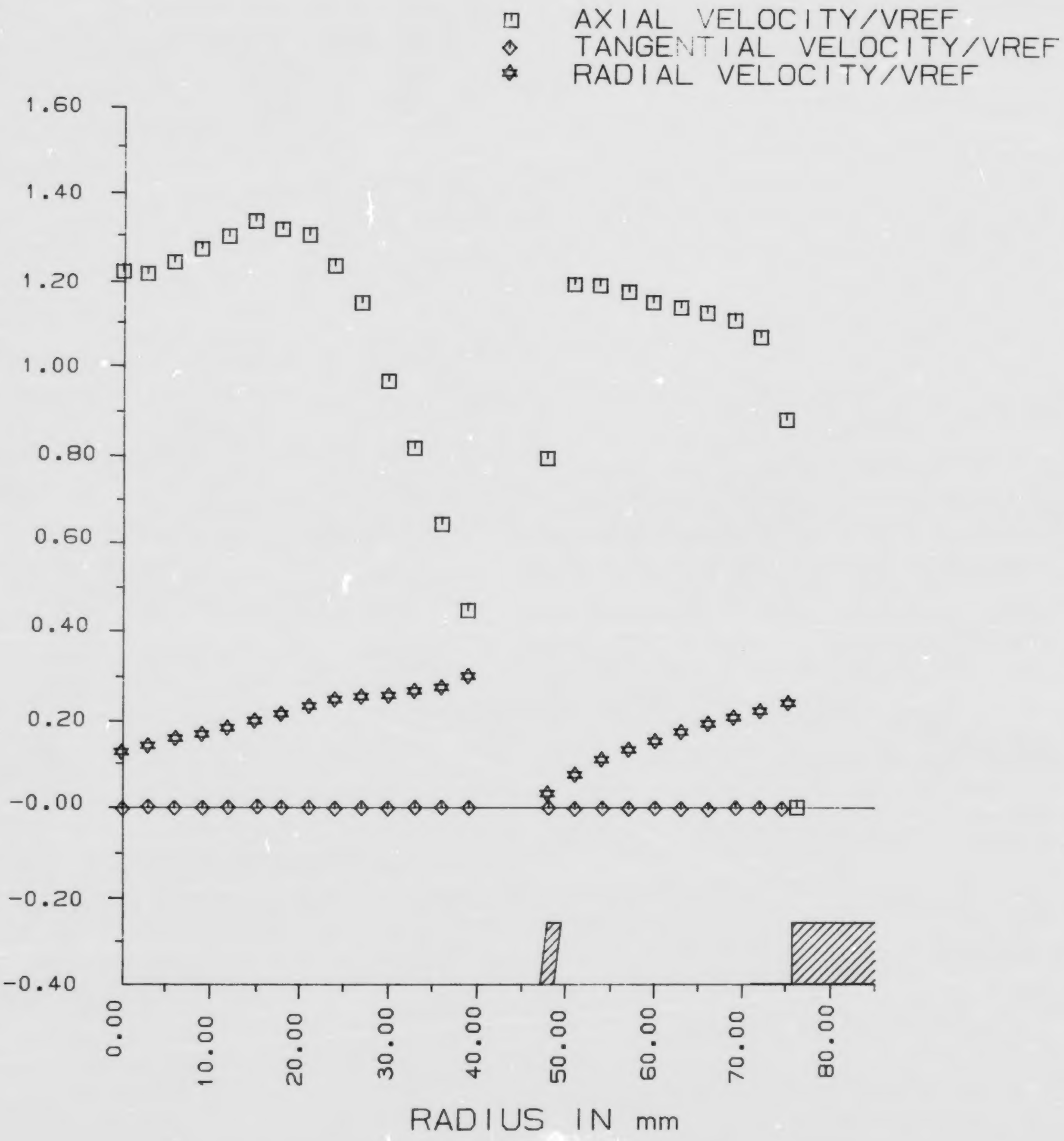


Fig. A1-2 - Velocity profiles at the swirl generator exit (low flow rate, swirl setting 0.0)

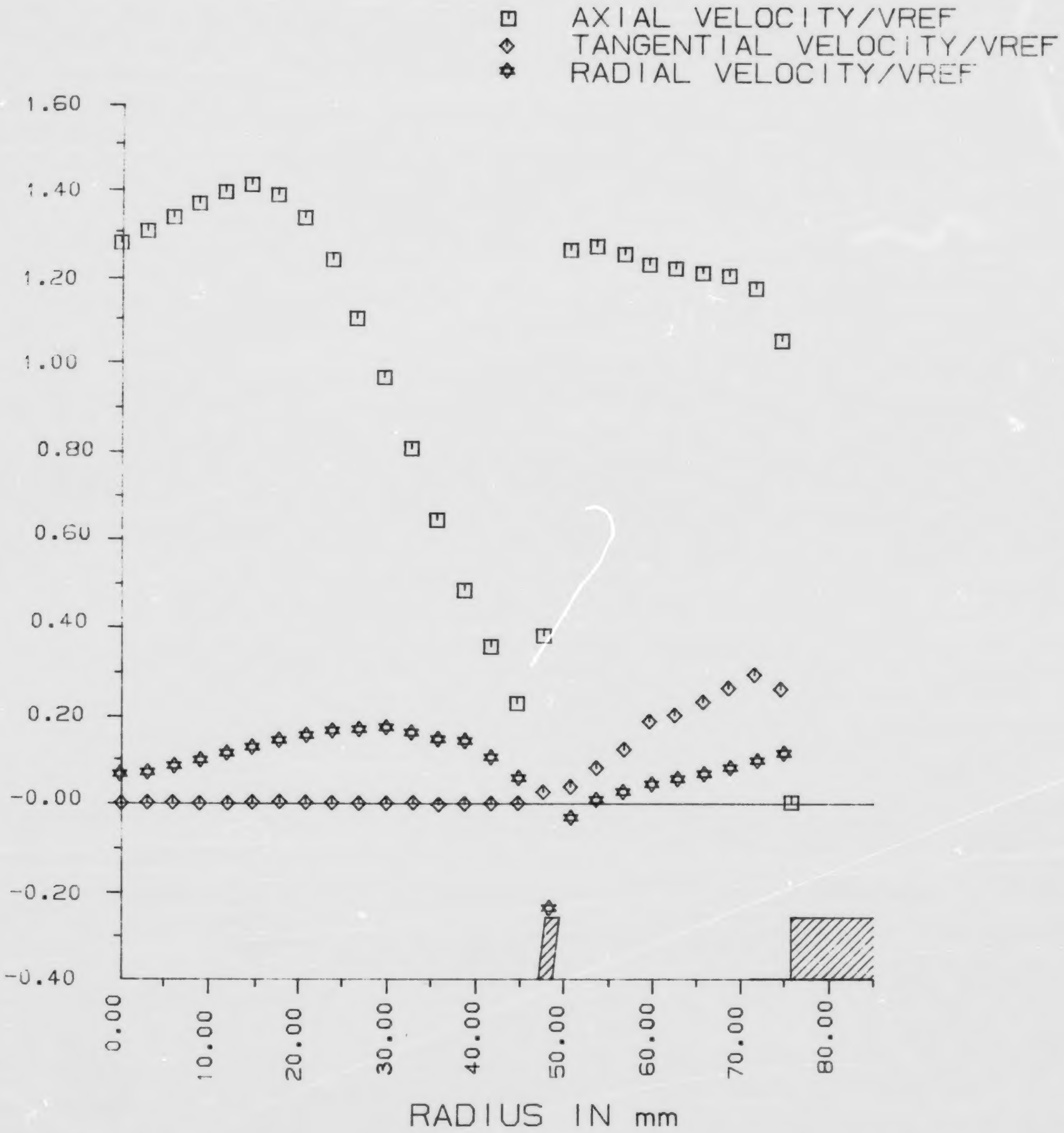


Fig. A1-3 - Velocity profiles at the swirl generator exit (high flow rate, swirl setting 0.5)

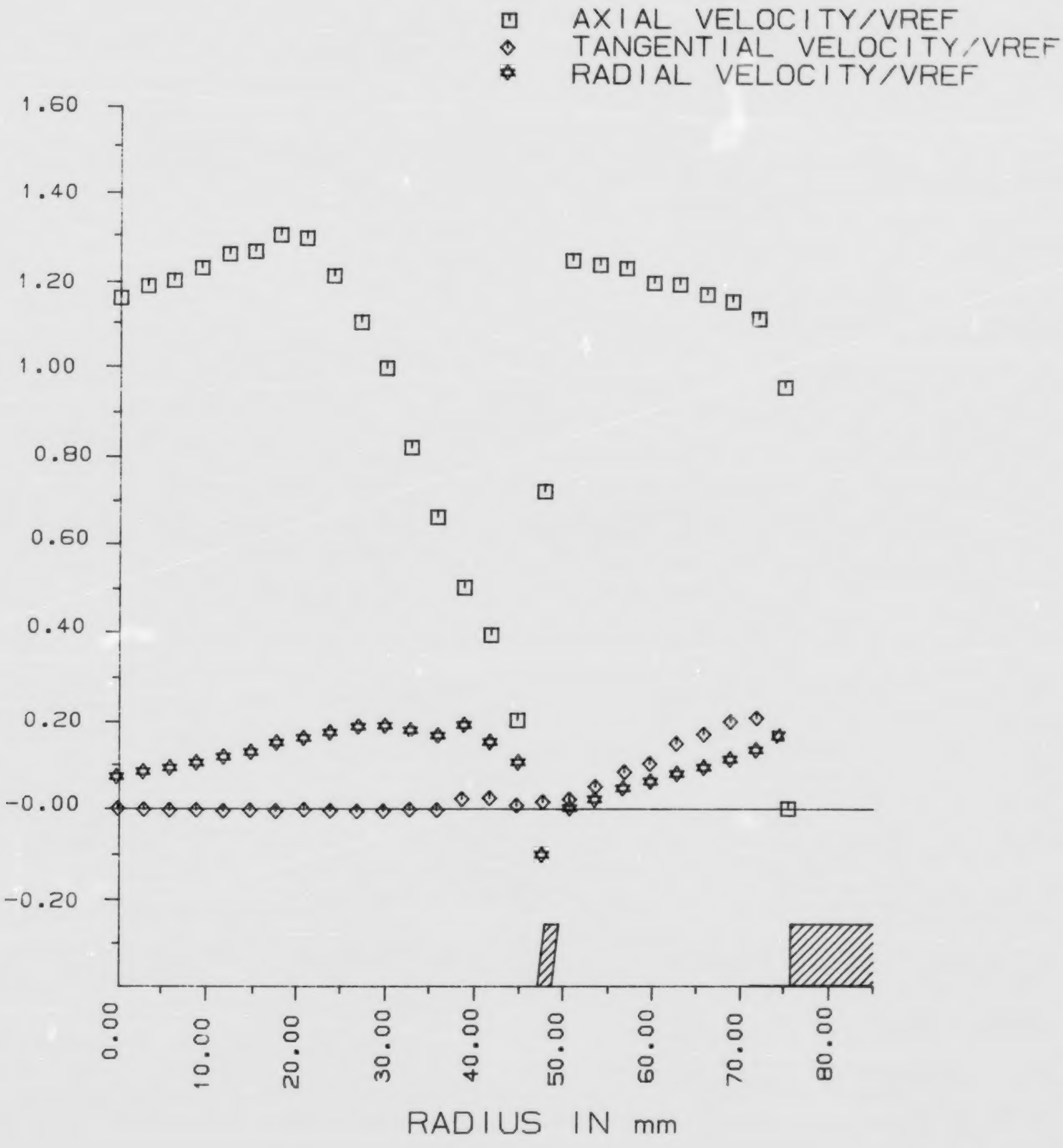


Fig. A1-4 - Velocity profiles at the swirl generator exit (low flow rate, swirl setting 0.5)

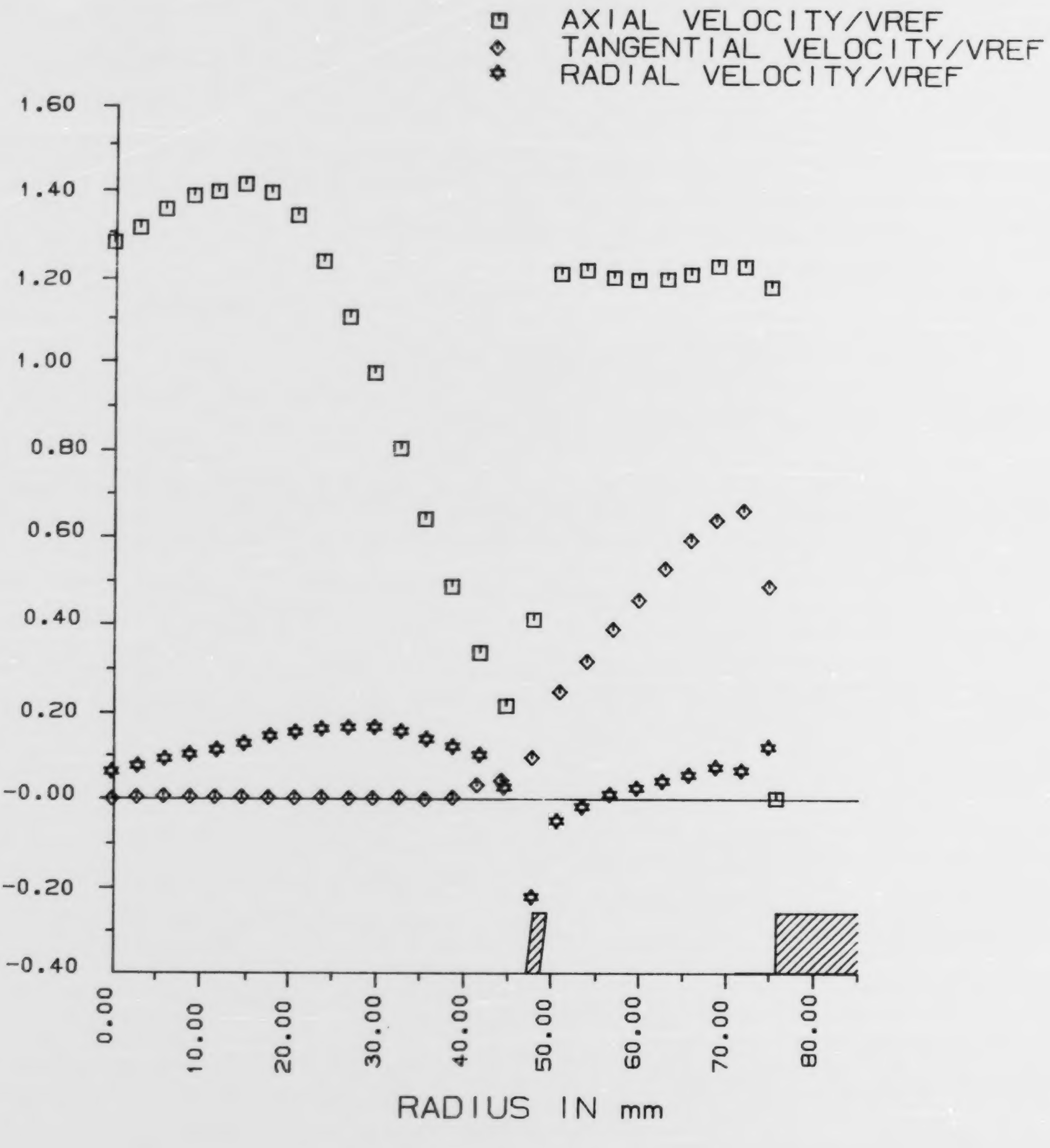


Fig. A1-5 - Velocity profiles at the swirl generator exit (high flow rate, swirl setting 1.0)

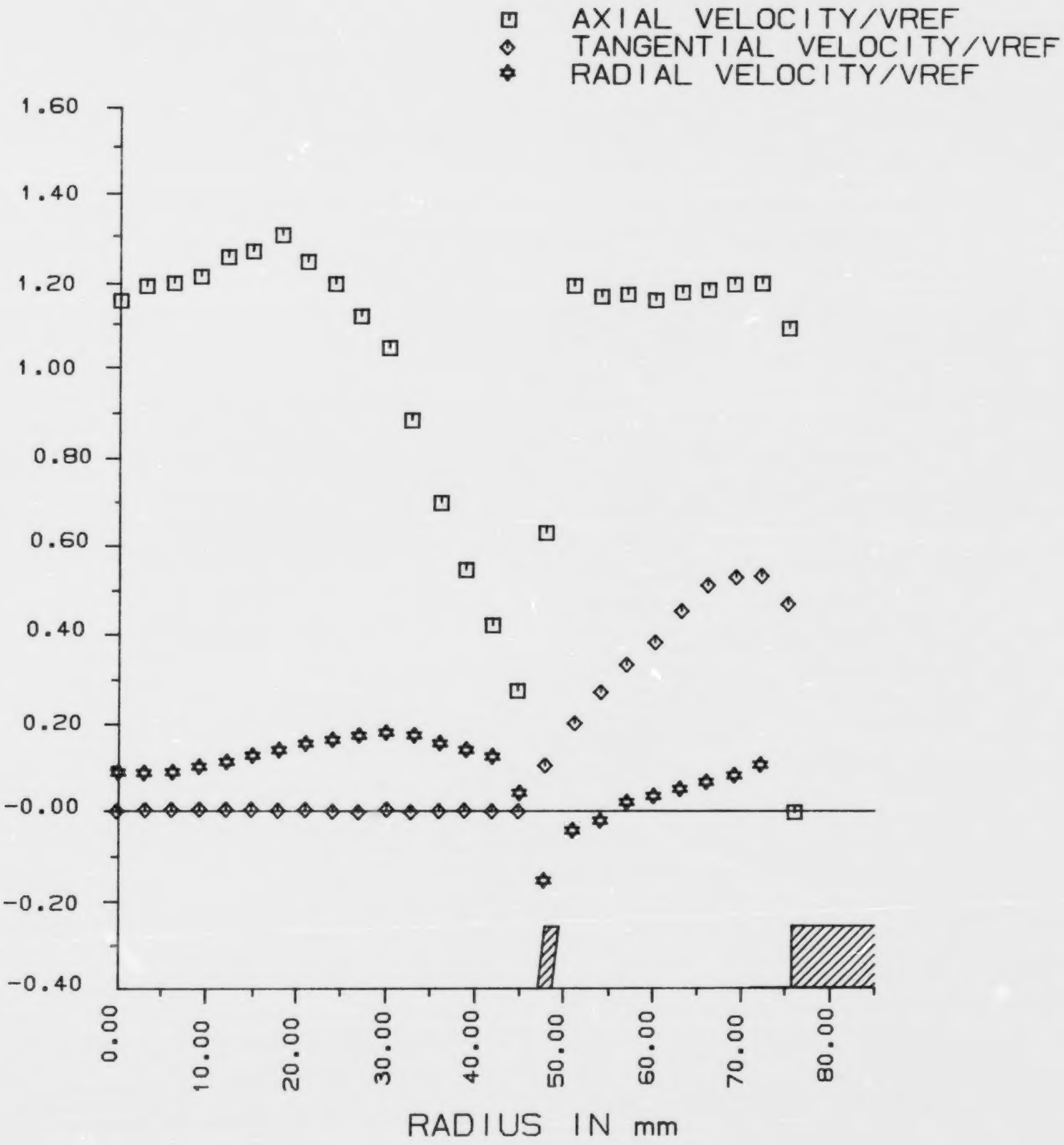


Fig. A1-6 - Velocity profiles at the swirl generator exit (low flow rate, swirl setting 1.0)

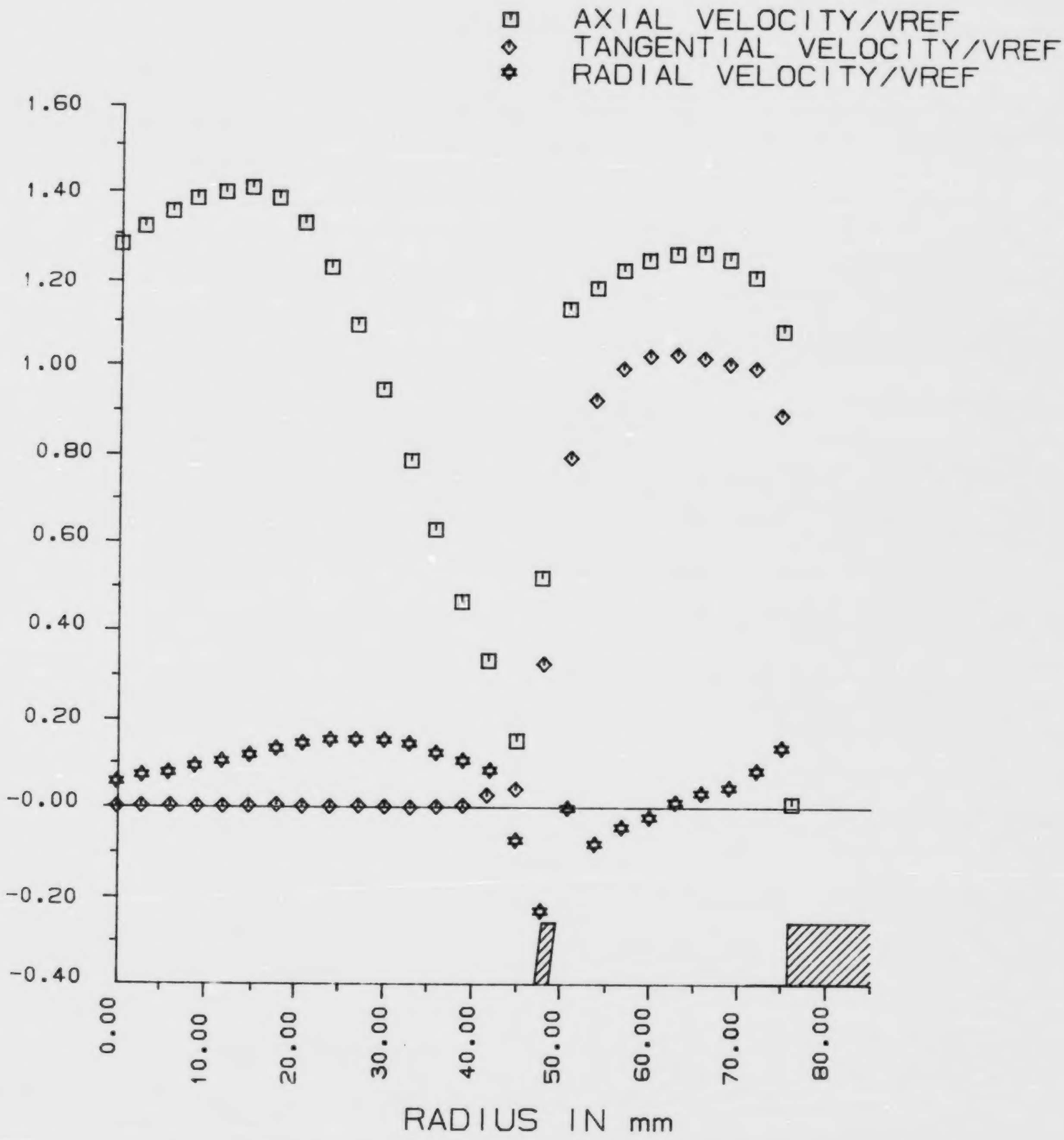


Fig. A1-7 - Velocity profiles at the swirl generator exit (high flow rate, swirl setting 2.0)

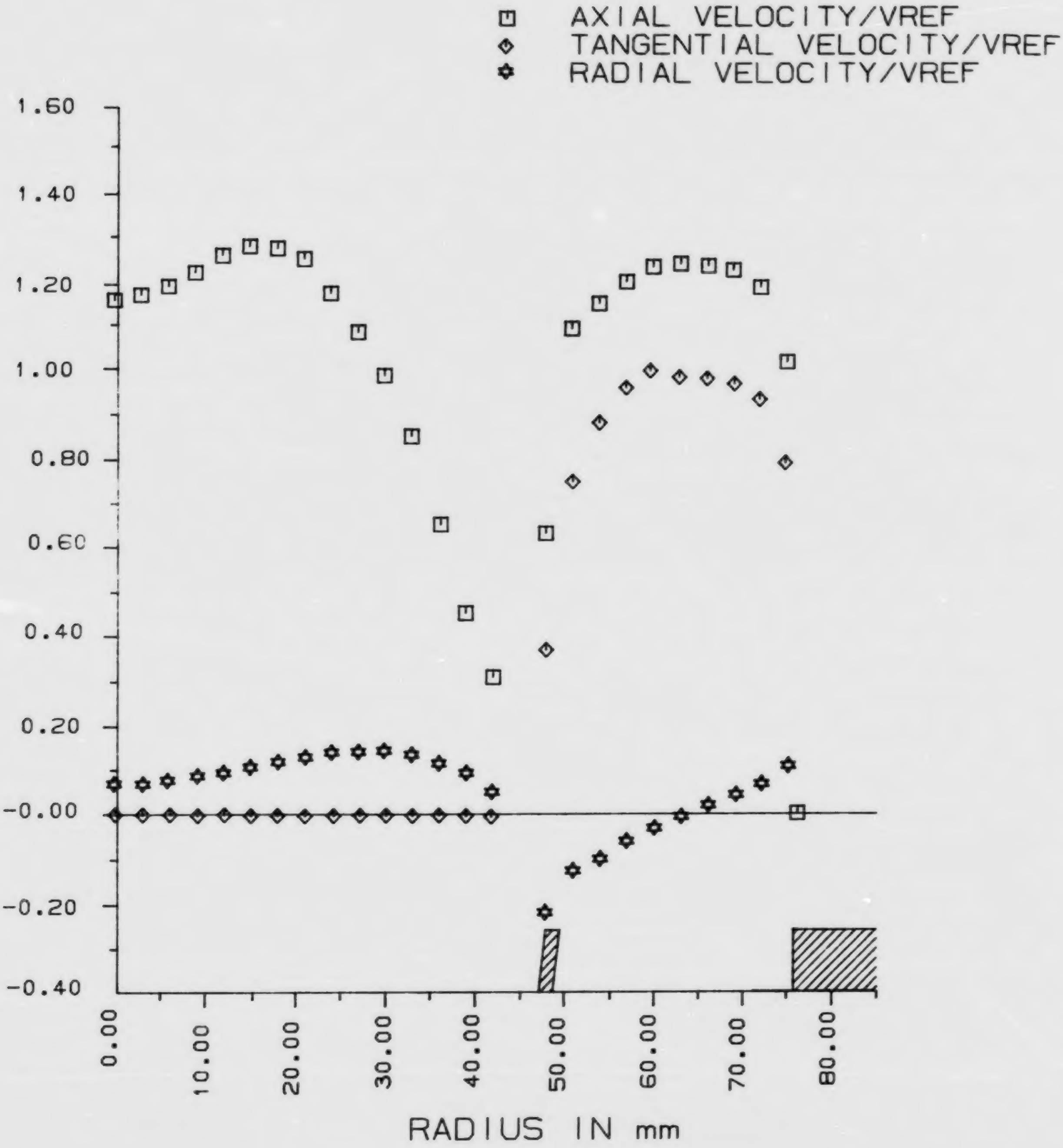


Fig. A1-8 - Velocity profiles at the swirl generator exit
(low flow rate, swirl setting 2.0)

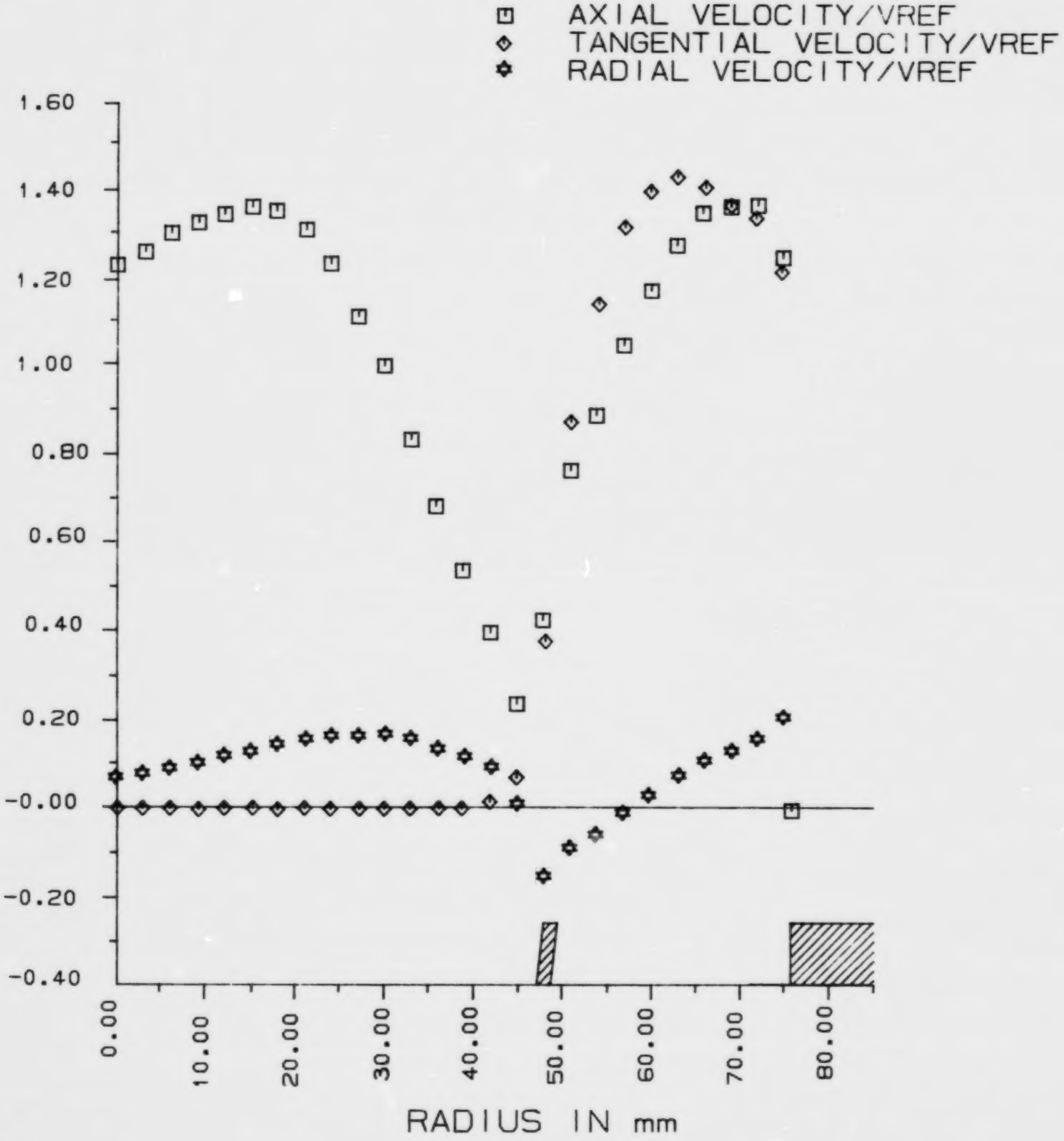


Fig. A1-9 - Velocity profiles at the swirl generator exit (high flow rate, swirl setting 3.0)

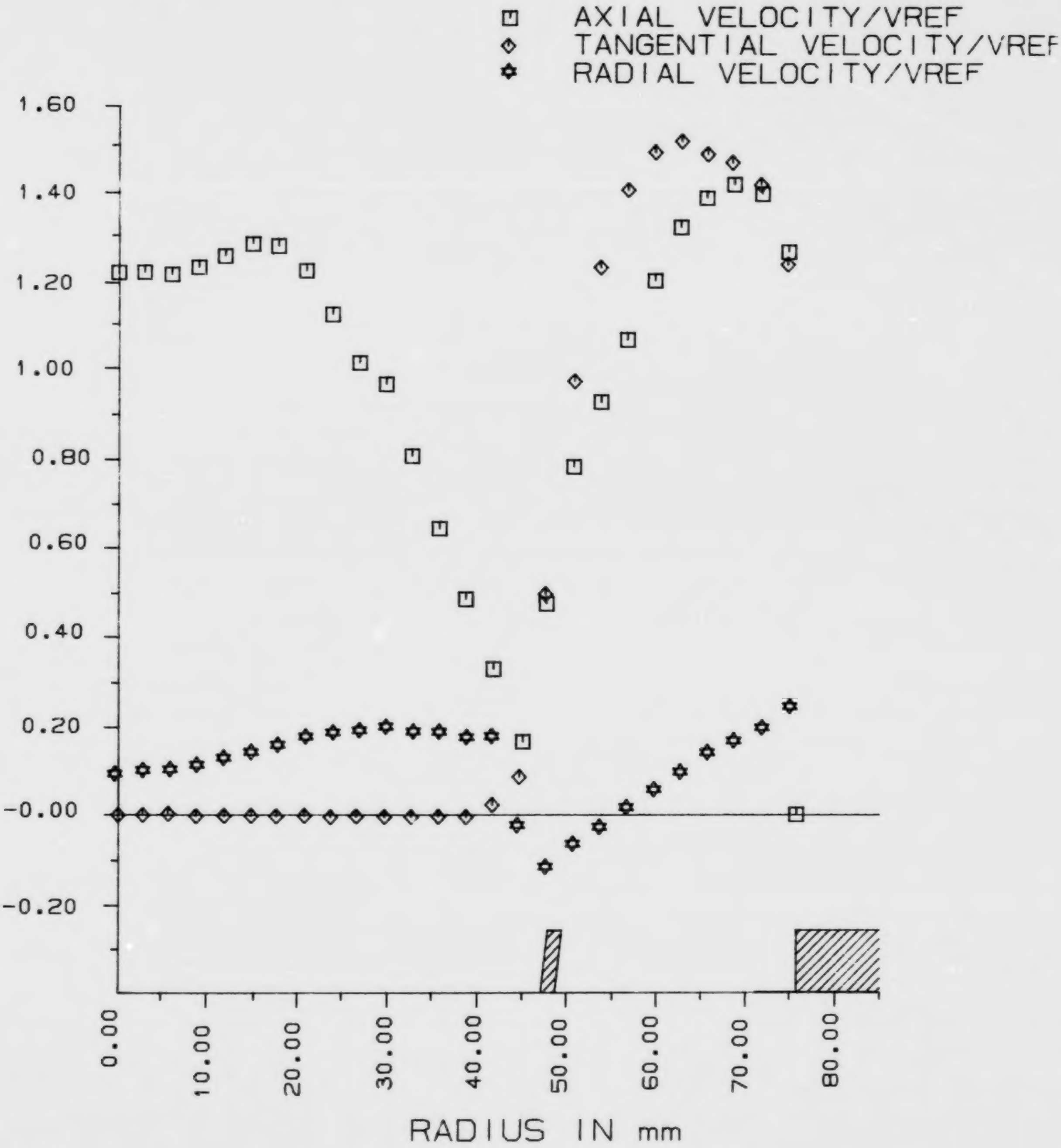


Fig. A1-10 - Velocity profiles at the swirl generator exit (low flow rate, swirl setting 3.0)

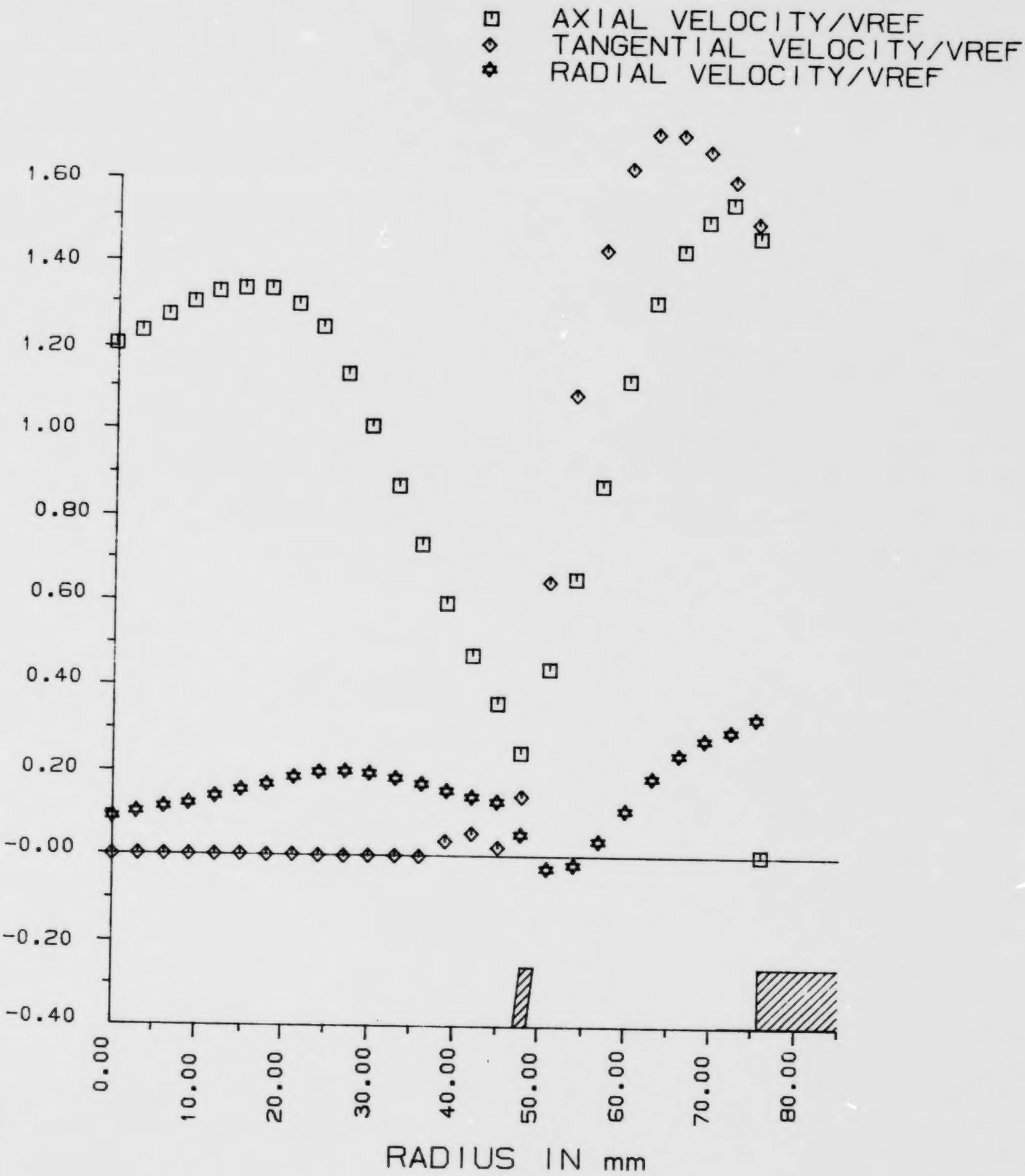


Fig. A1-11 - Velocity profiles at the swirl generator exit (high flow rate, swirl setting 4.0)

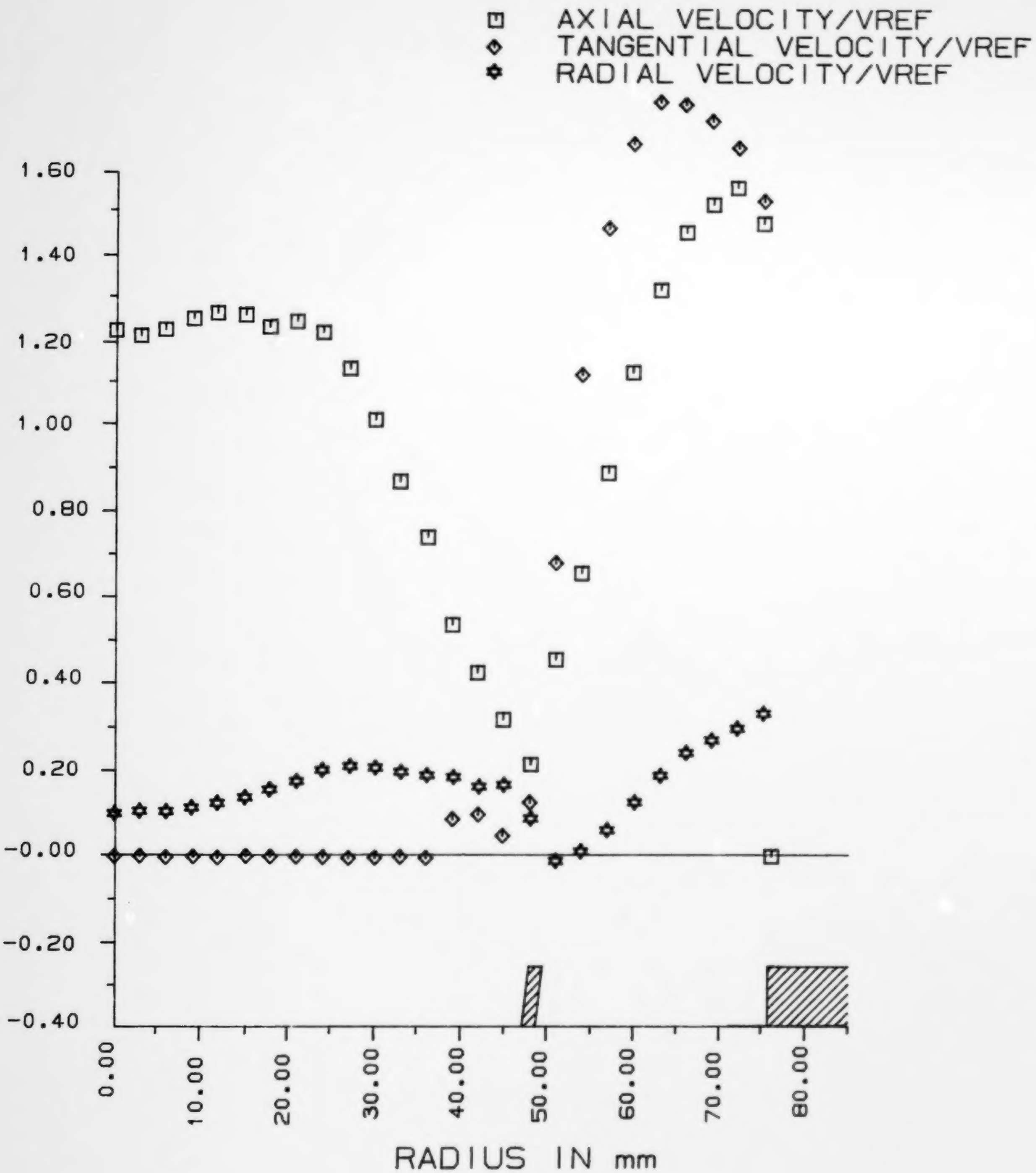


Fig. A1-12 - Velocity profiles at the swirl generator exit (low flow rate, swirl setting 4.0)

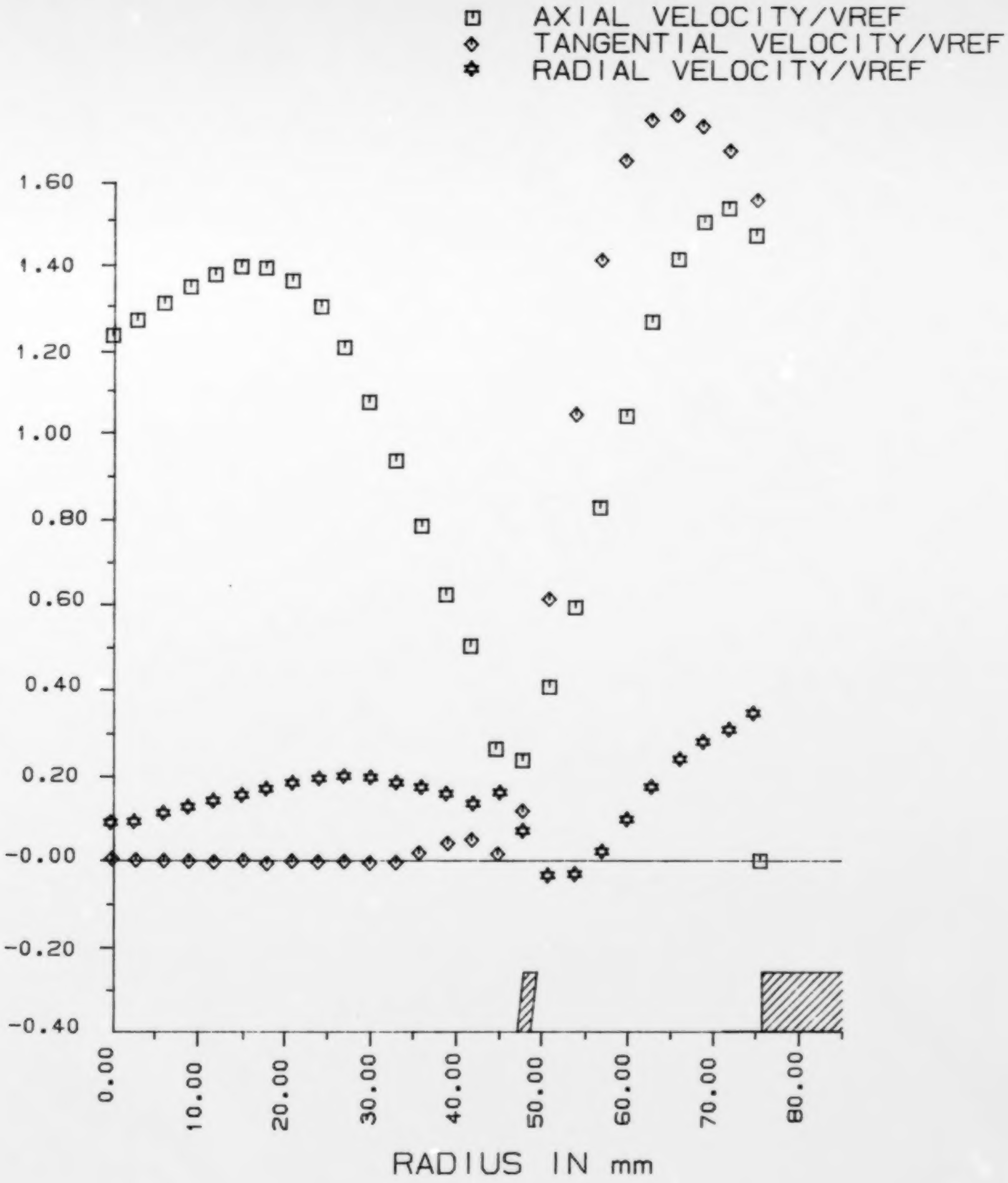


Fig. A1-13 - Velocity profiles at the swirl generator exit (high flow rate, swirl setting 4.5)

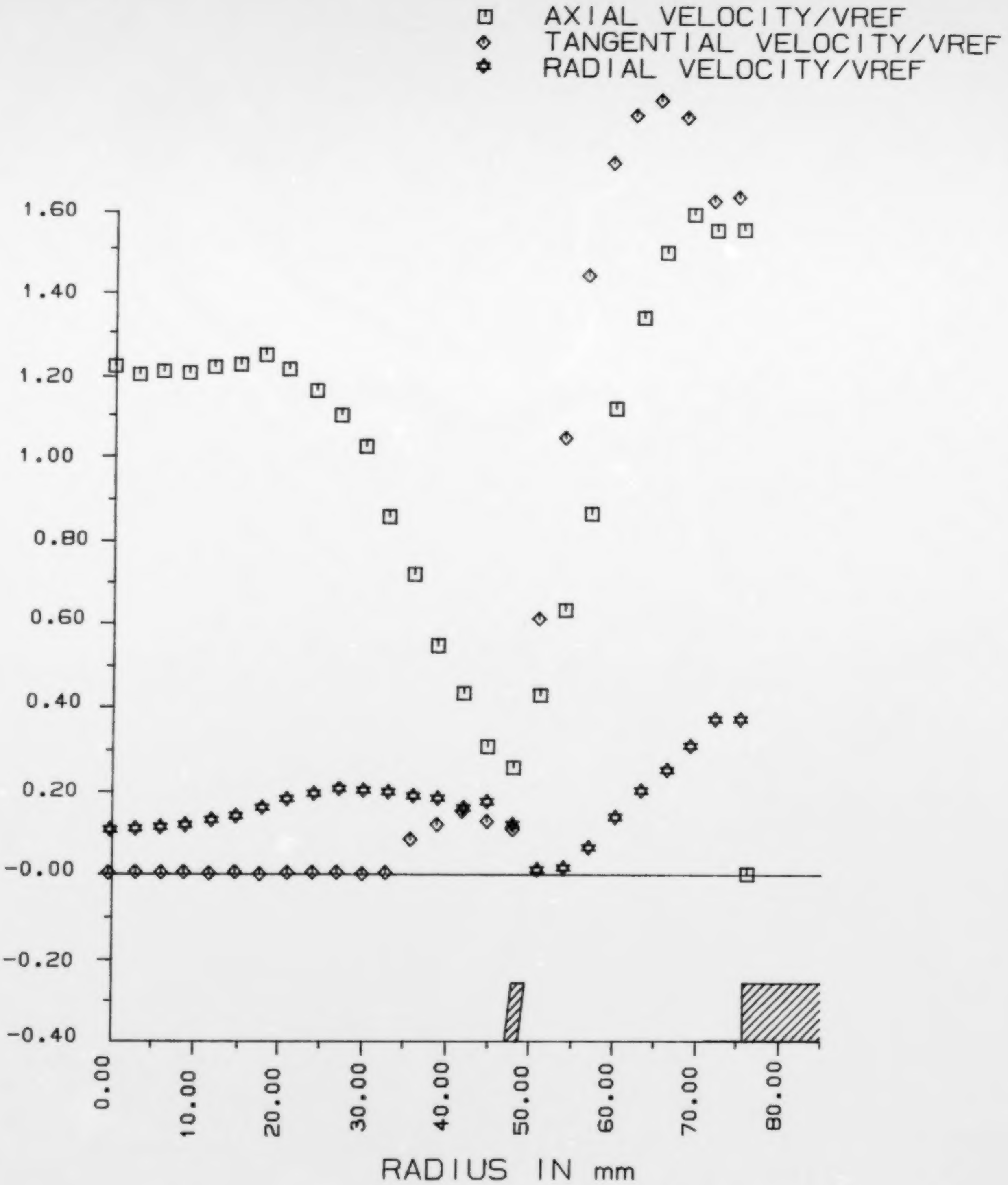


Fig. A1-14 - Velocity profiles at the swirl generator exit (low flow rate, swirl setting 4.5)

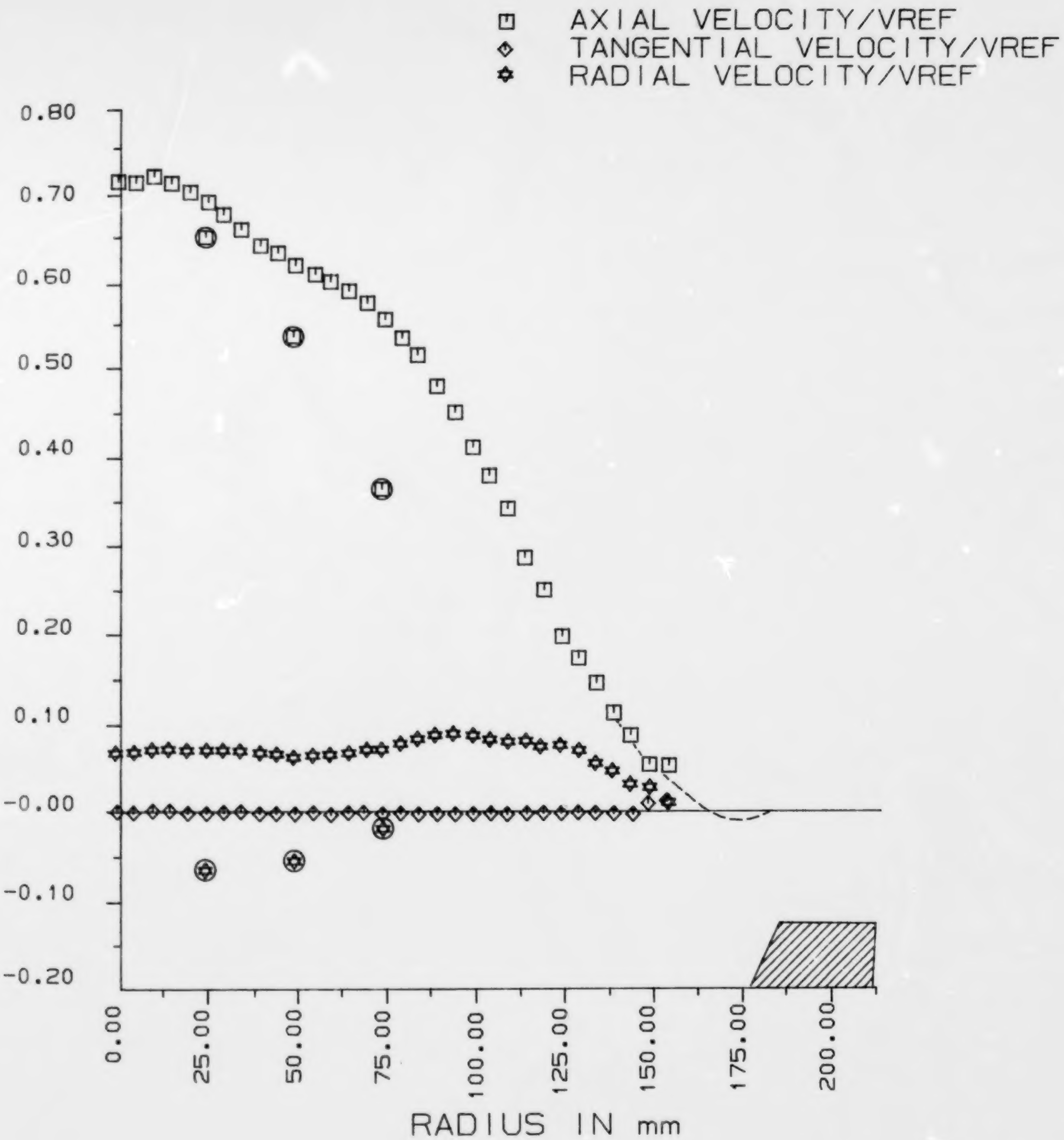


Fig. A1-15 - Velocity profiles at the quarl exit (high flow rate, swirl setting 0.0)

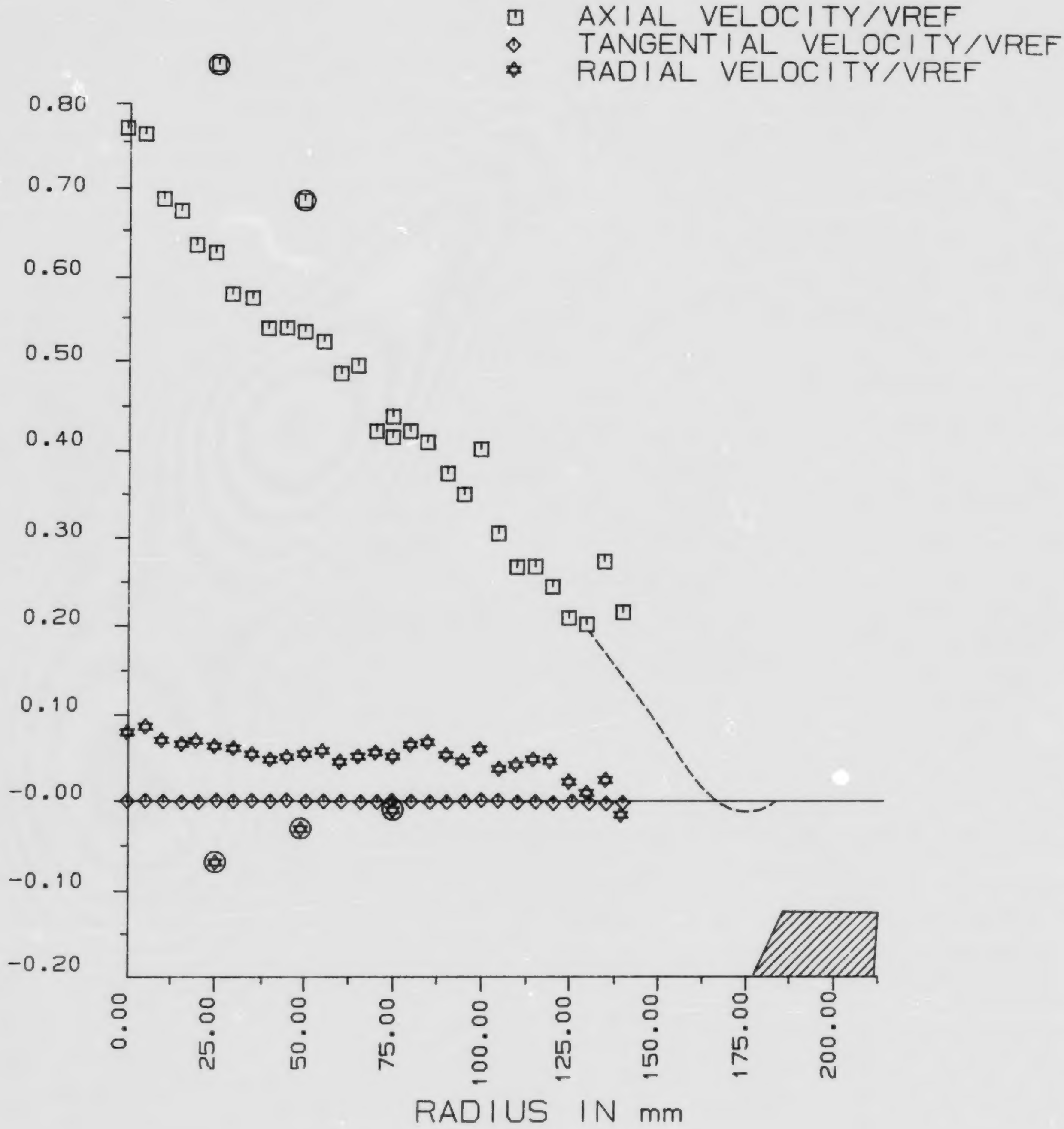


Fig. A1-16 - Velocity profiles at the quarl exit
(low flow rate, swirl setting 0.0)

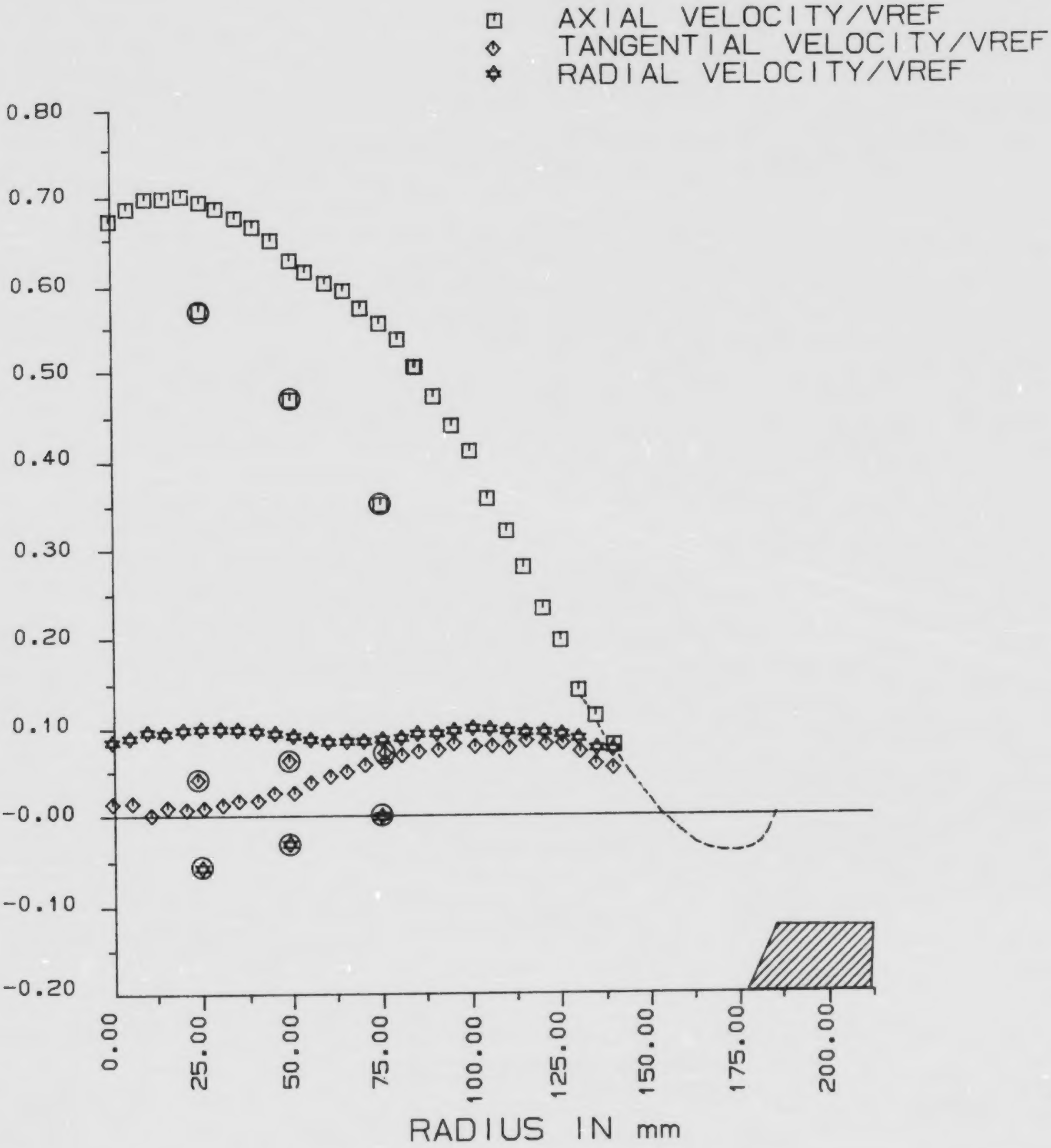


Fig. A1-17 - Velocity profiles at the quarl exit (high flow rate, swirl setting 0.5)

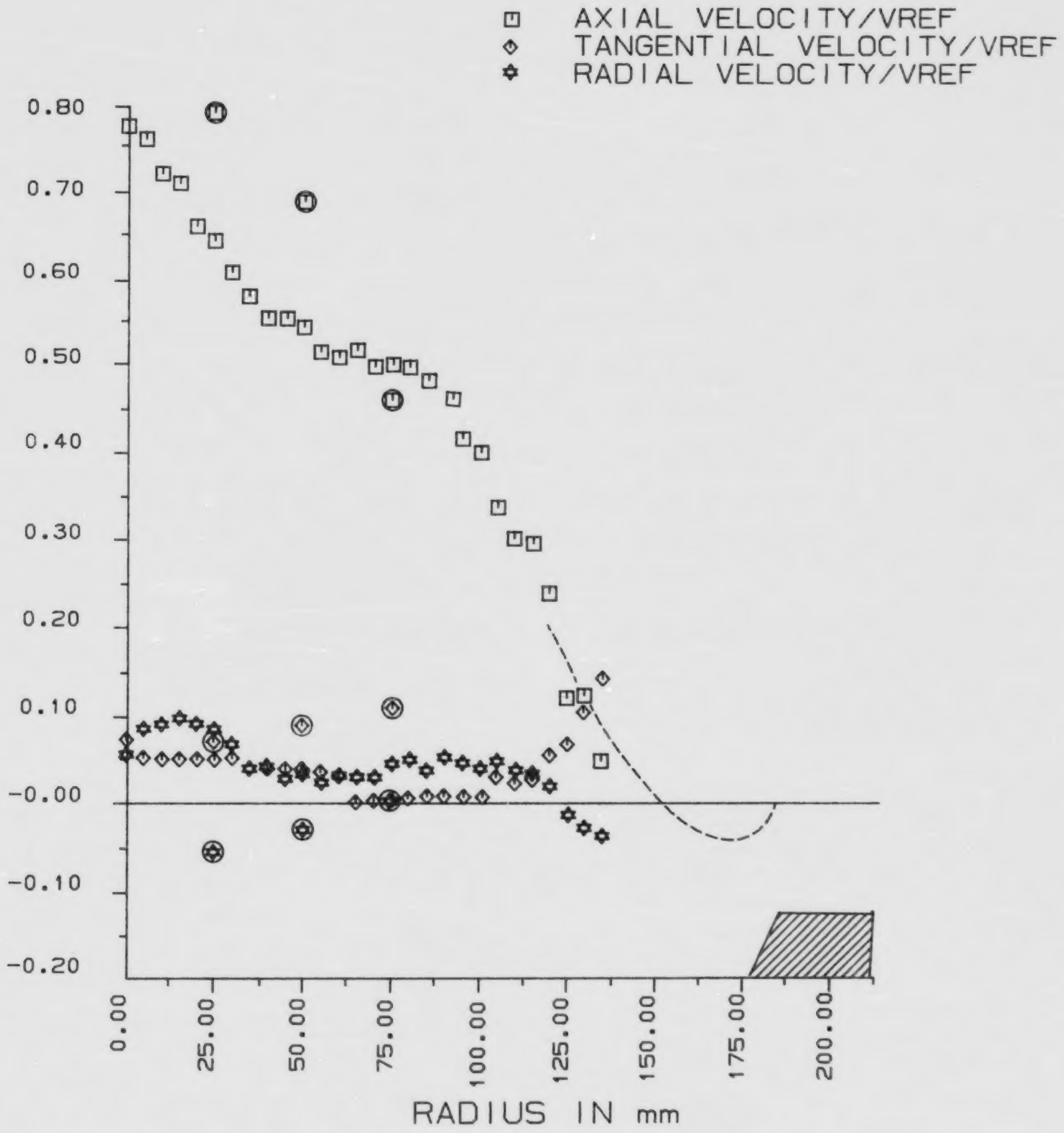


Fig. A1-18 - Velocity profiles at the quarl exit
(low flow rate, swirl setting 0.5)

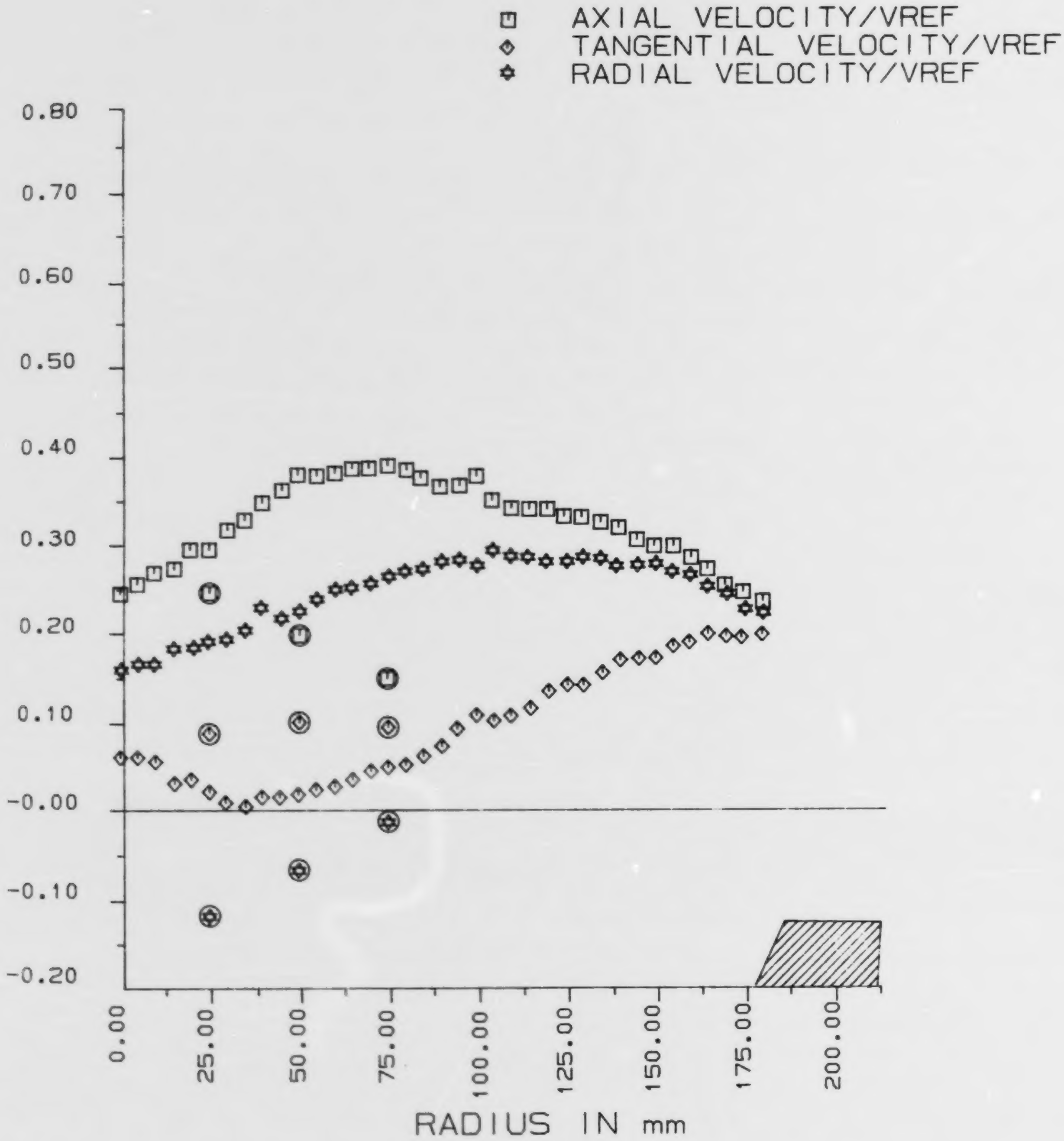


Fig. A1-19 - Velocity profiles at the quarl exit (high flow rate, swirl setting 1.0)

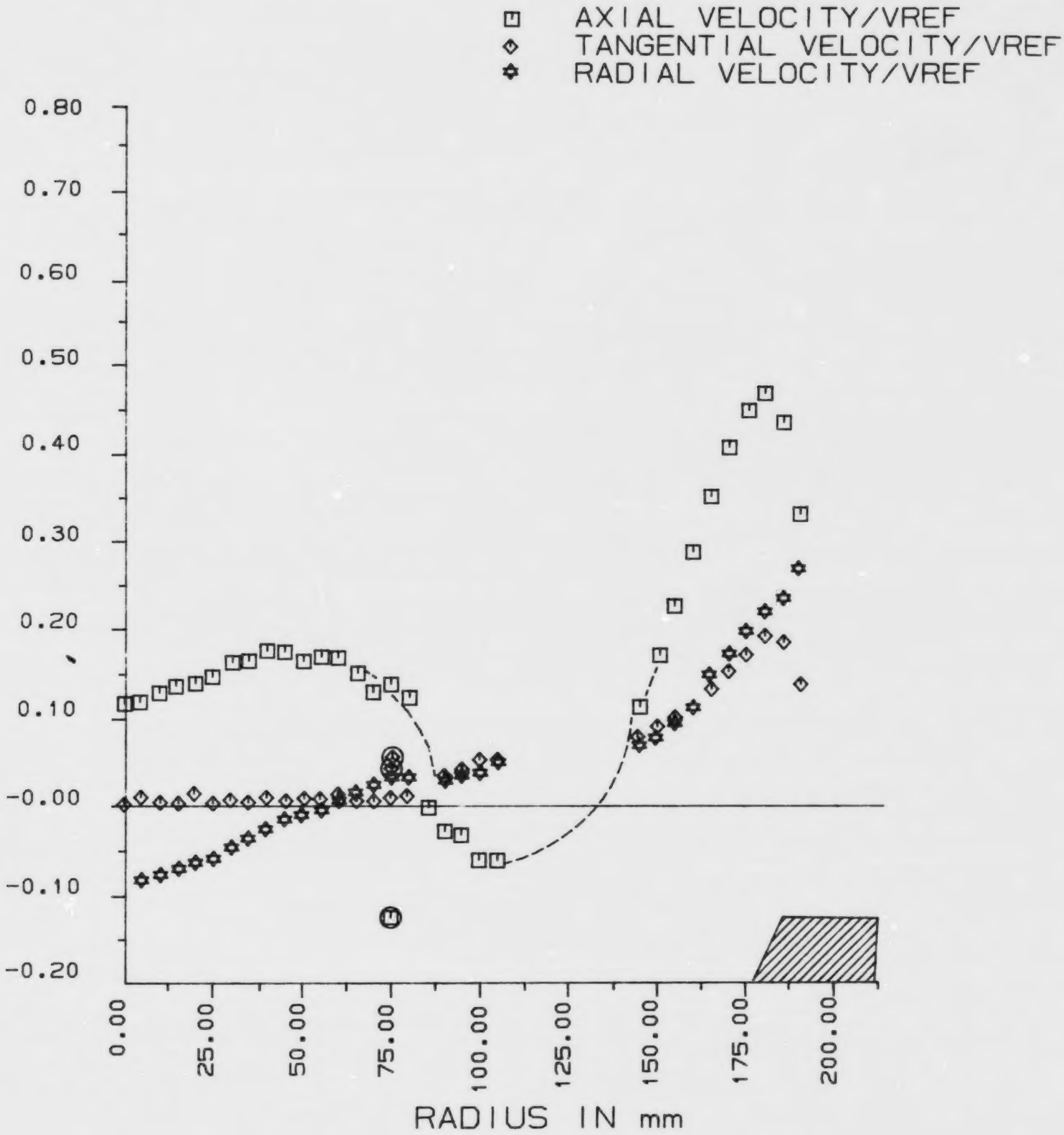


Fig. A1-20 - Velocity profiles at the quarl exit (high flow rate, swirl setting 2.0)

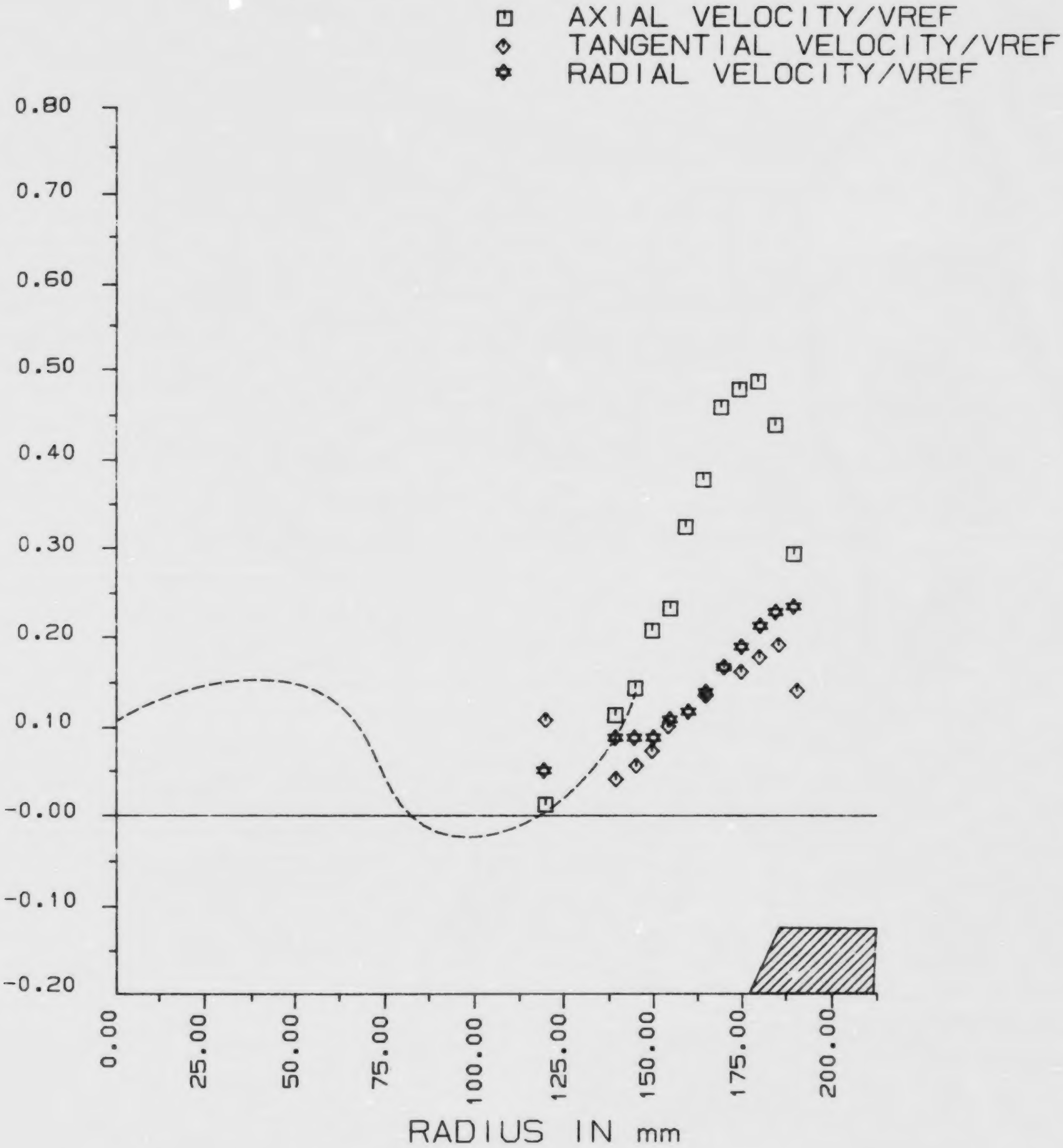


Fig. A1-21 - Velocity profiles at the quarl exit (low flow rate, swirl setting 2.0)

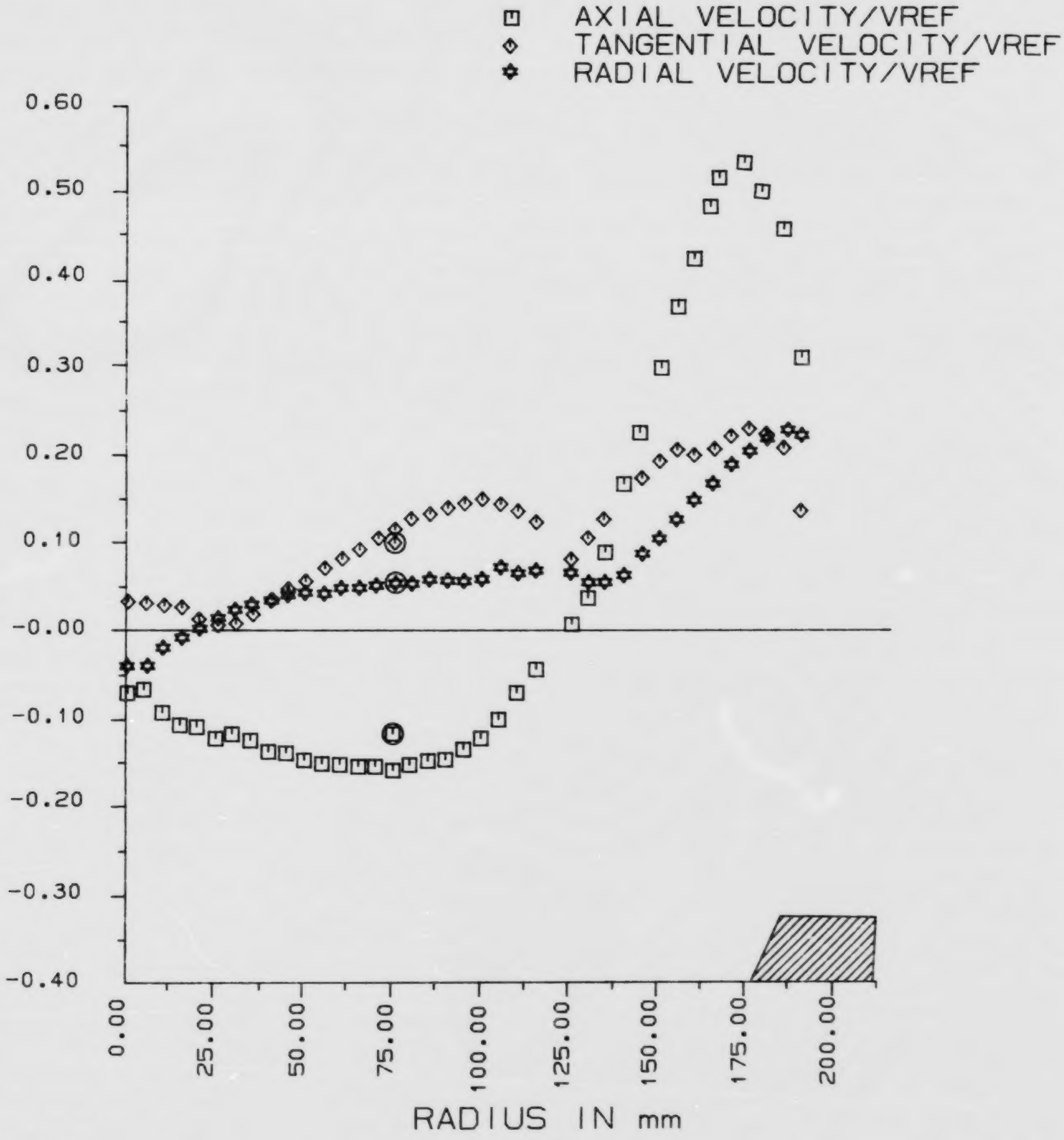


Fig. A1-22 - Velocity profiles at the quarl exit (high flow rate, swirl setting 3.0)

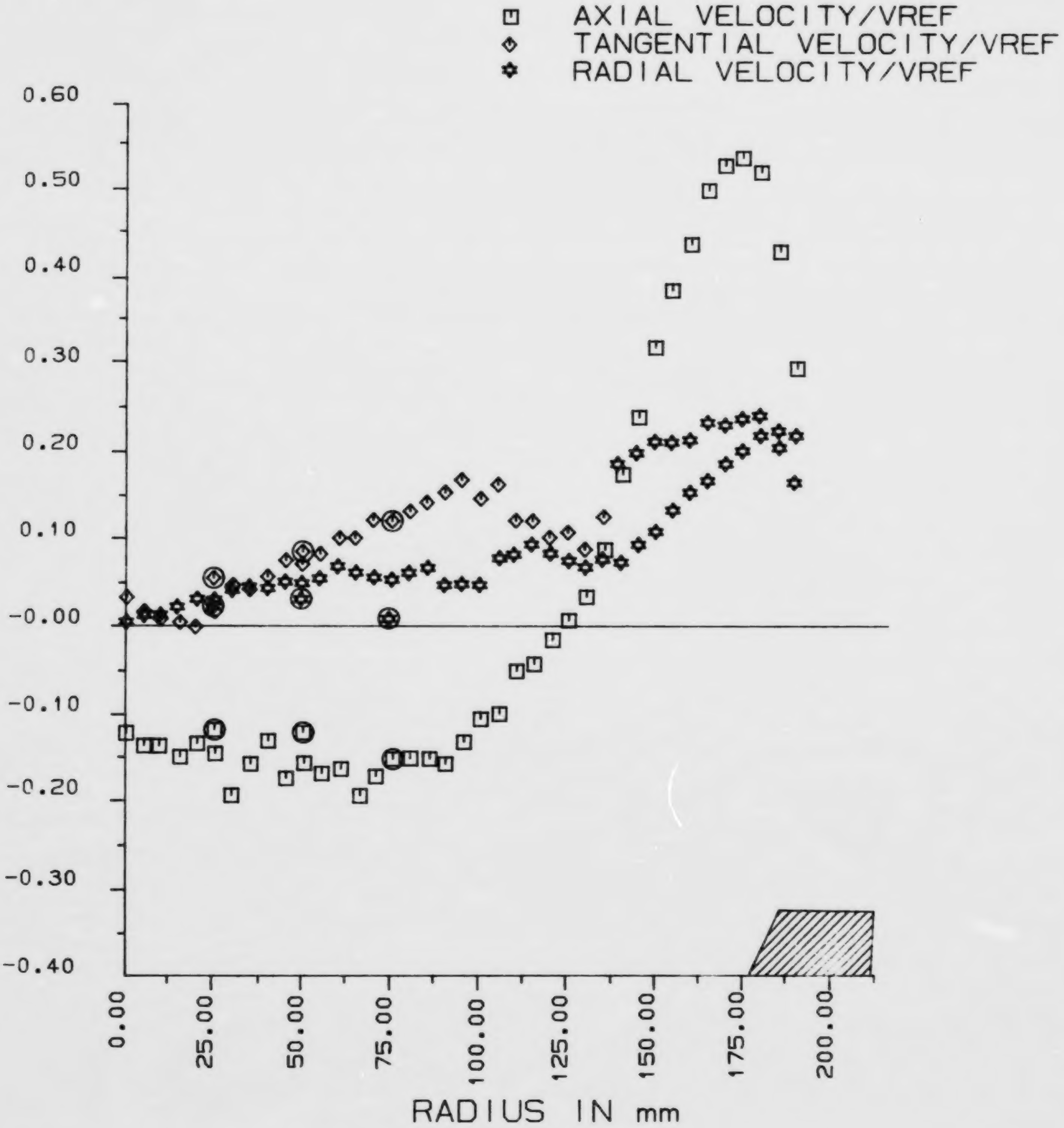


Fig. A1-23 - Velocity profiles at the quarl exit
(low flow rate, swirl setting 3.0)

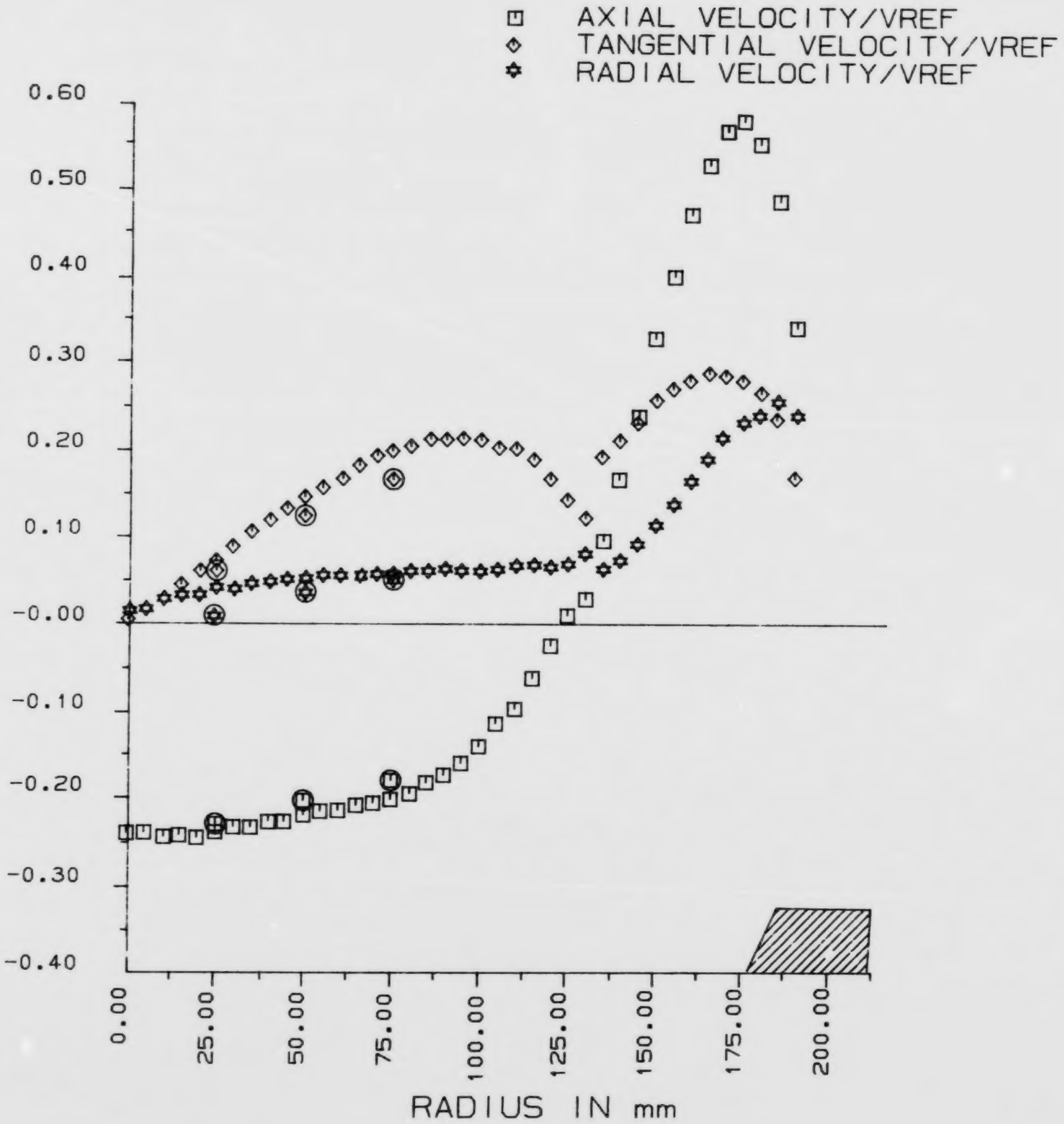


Fig. A1-24 - Velocity profiles at the quarl exit (high flow rate, swirl setting 4.0)

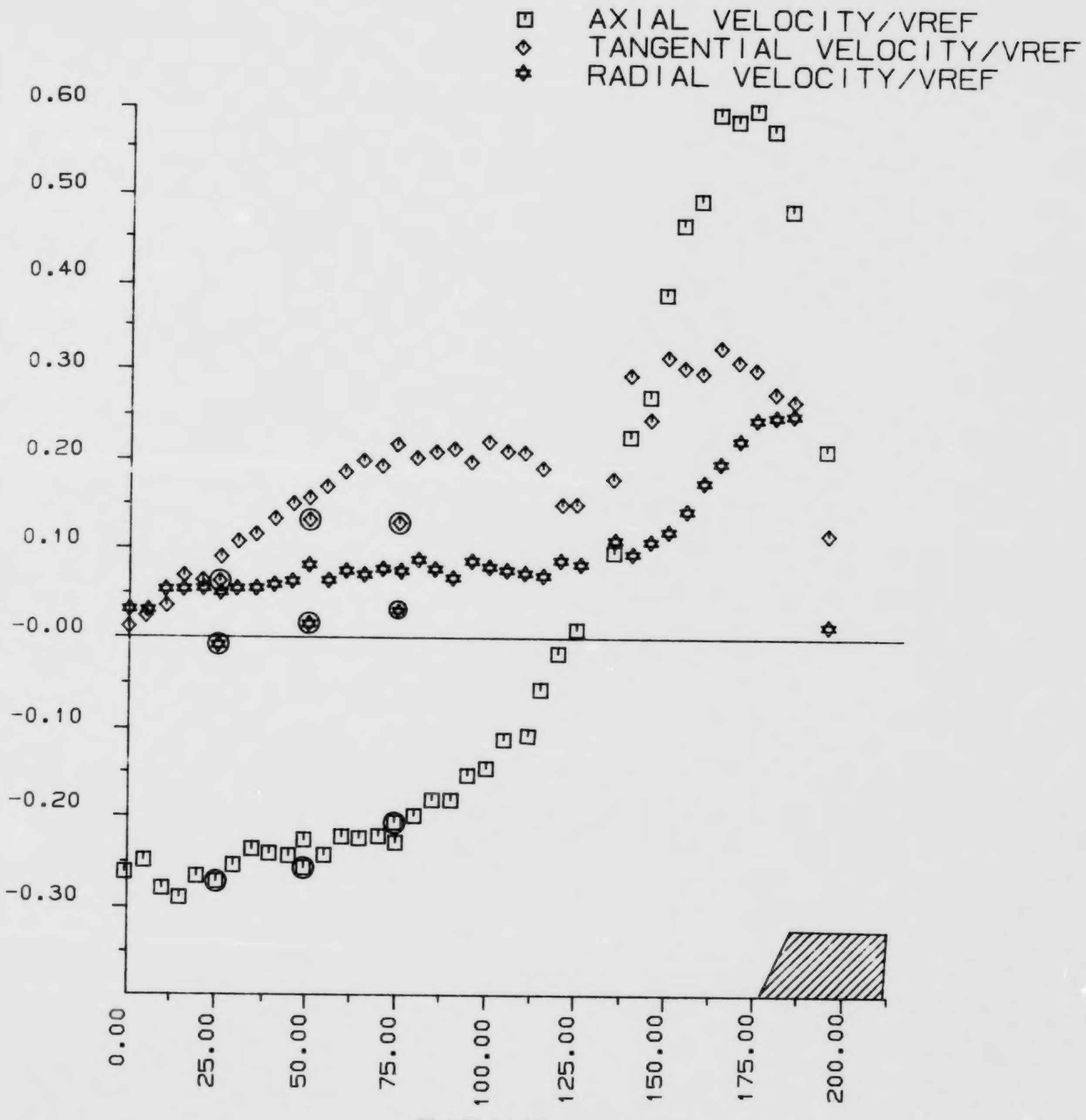


Fig. A1-25 - Velocity profiles at the quarl exit (low flow rate, swirl setting 4.0)

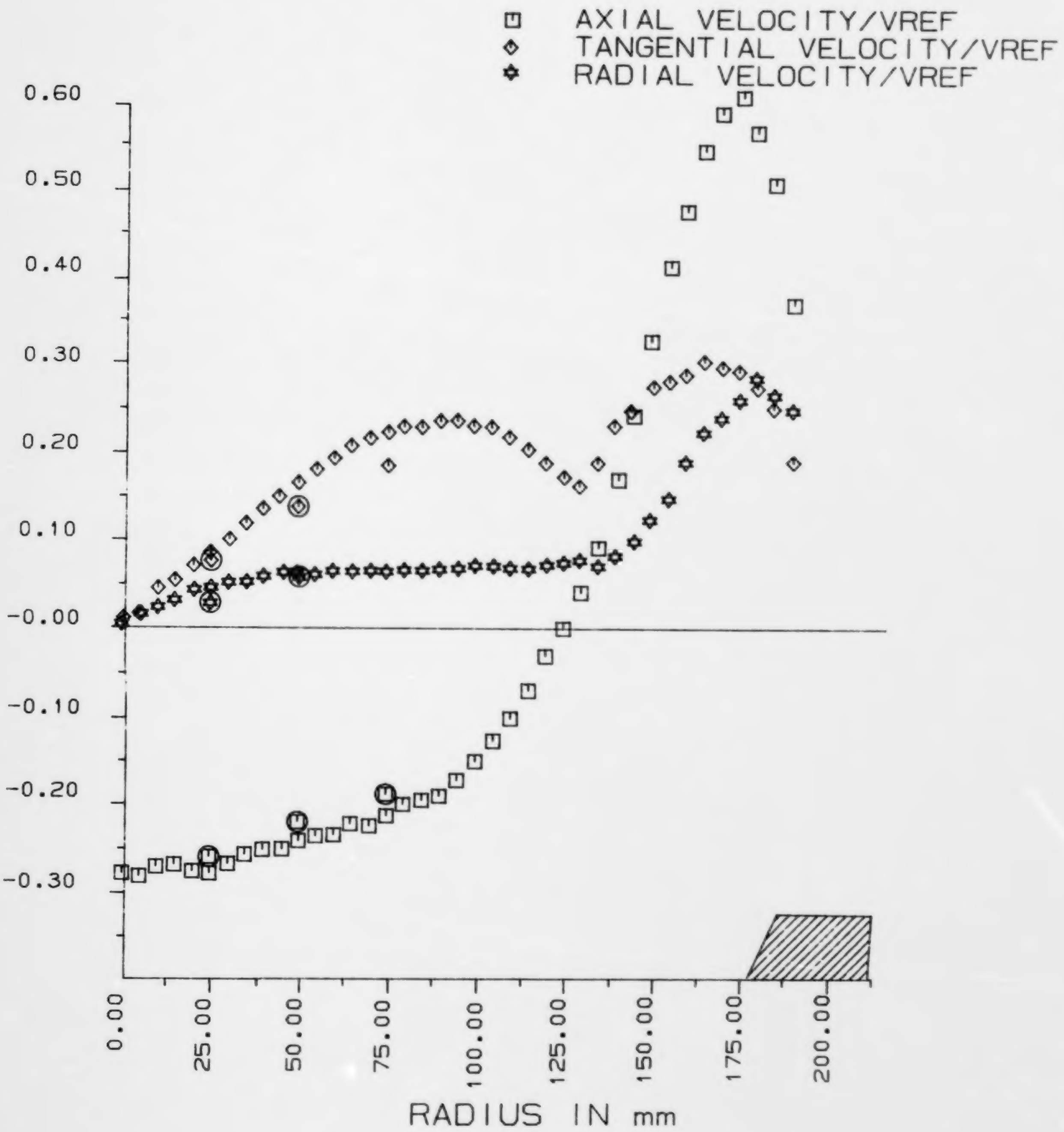


Fig. A1-26 - Velocity profiles at the quarl exit (high flow rate, swirl setting 4.5)

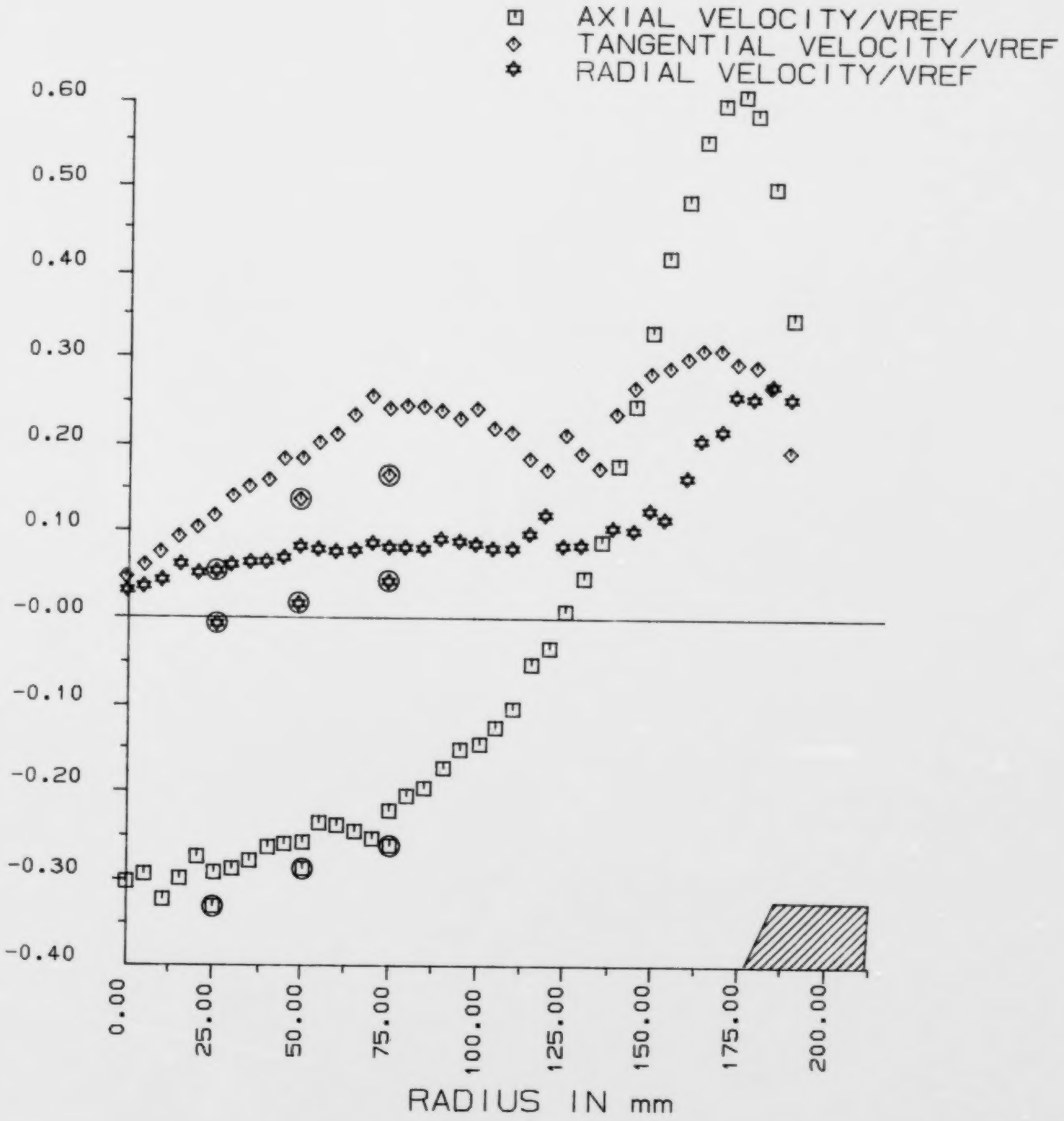


Fig. A1-27 - Velocity profiles at the quarl exit (low flow rate, swirl setting 4.5)

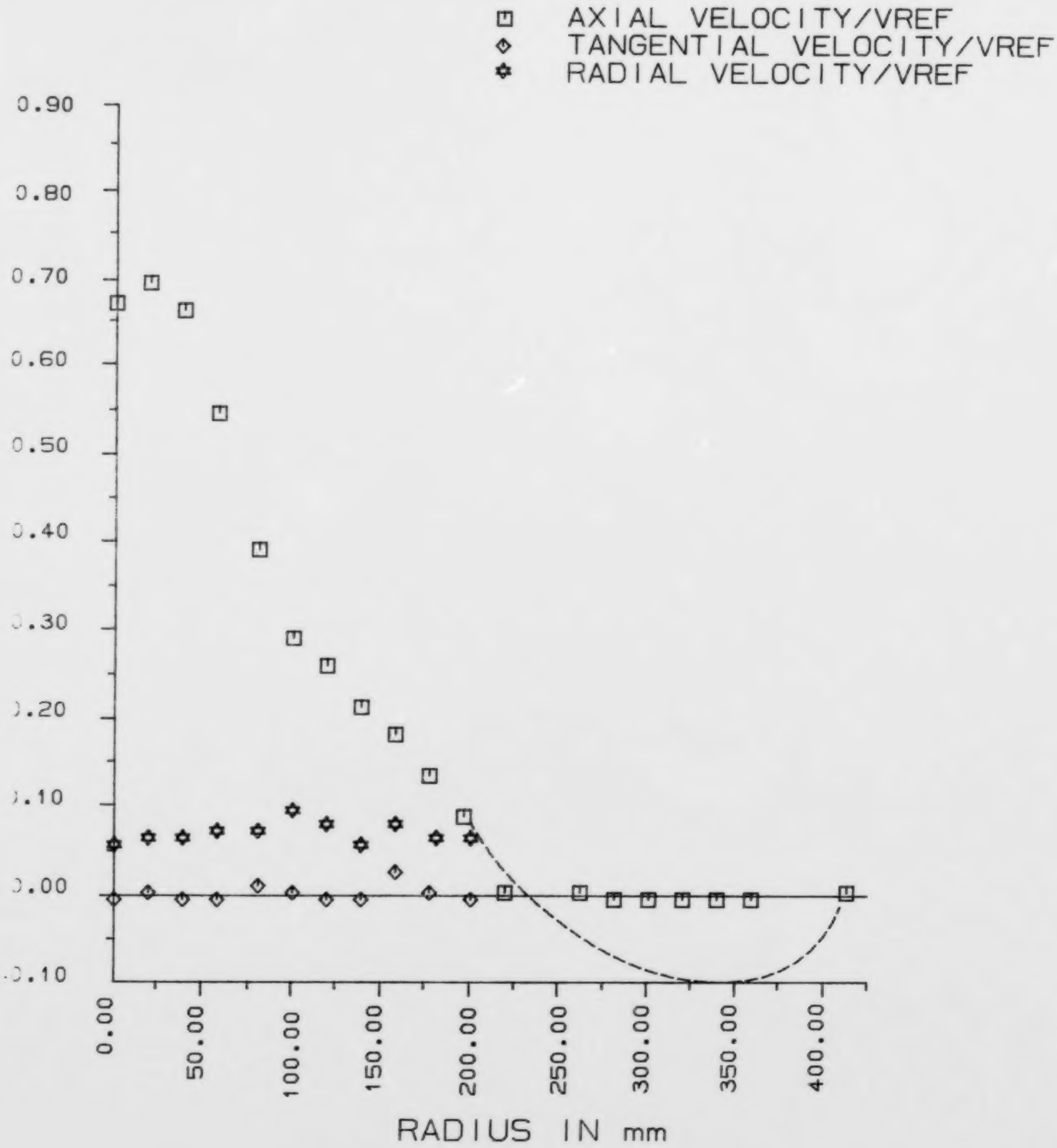


Fig. A1-28 - Velocity profiles at the first tunnel port (high flow rate, swirl setting 0.0)

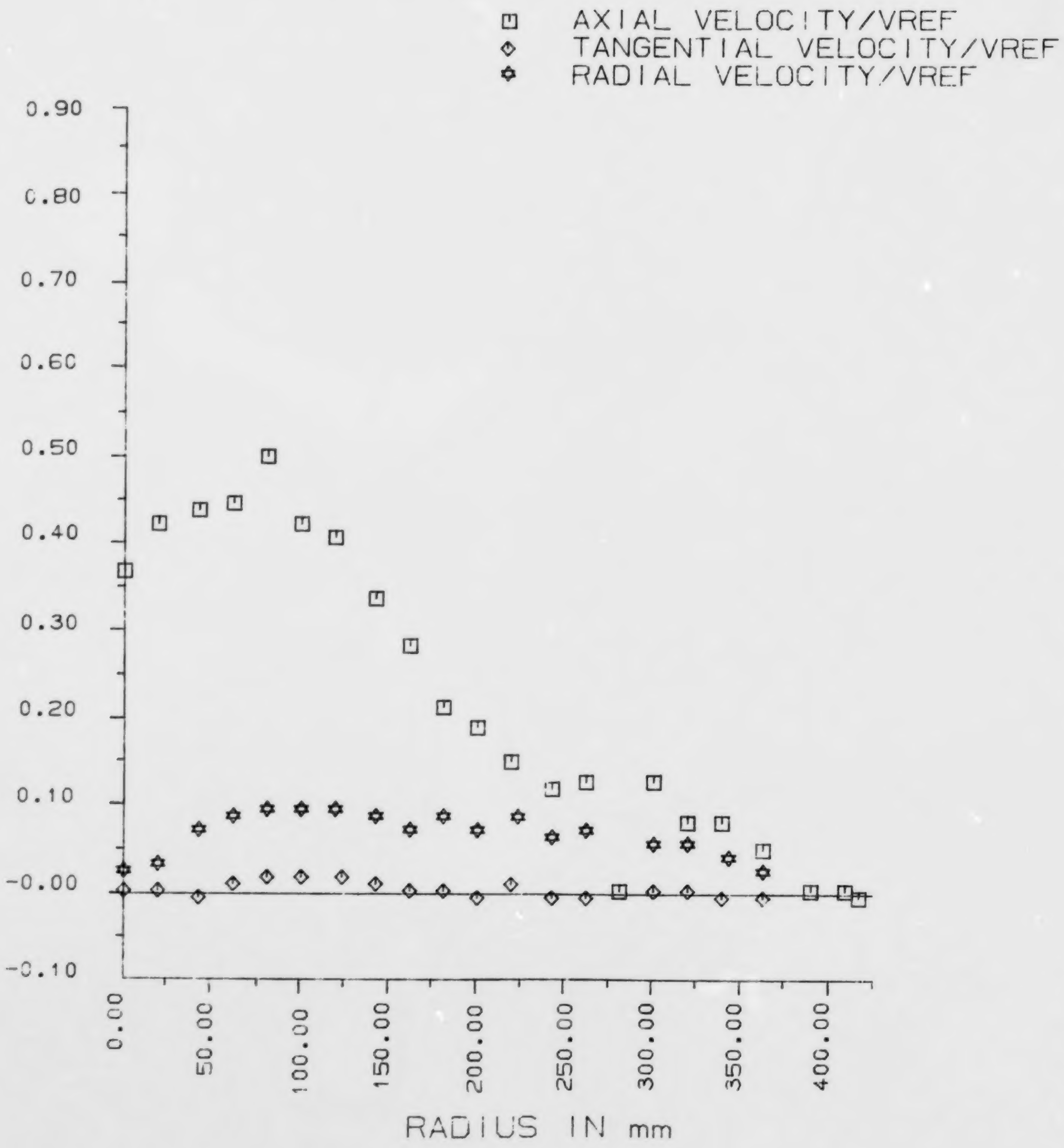


Fig. A1-29 - Velocity profiles at the second tunnel port (high flow rate, swirl setting 0.0)

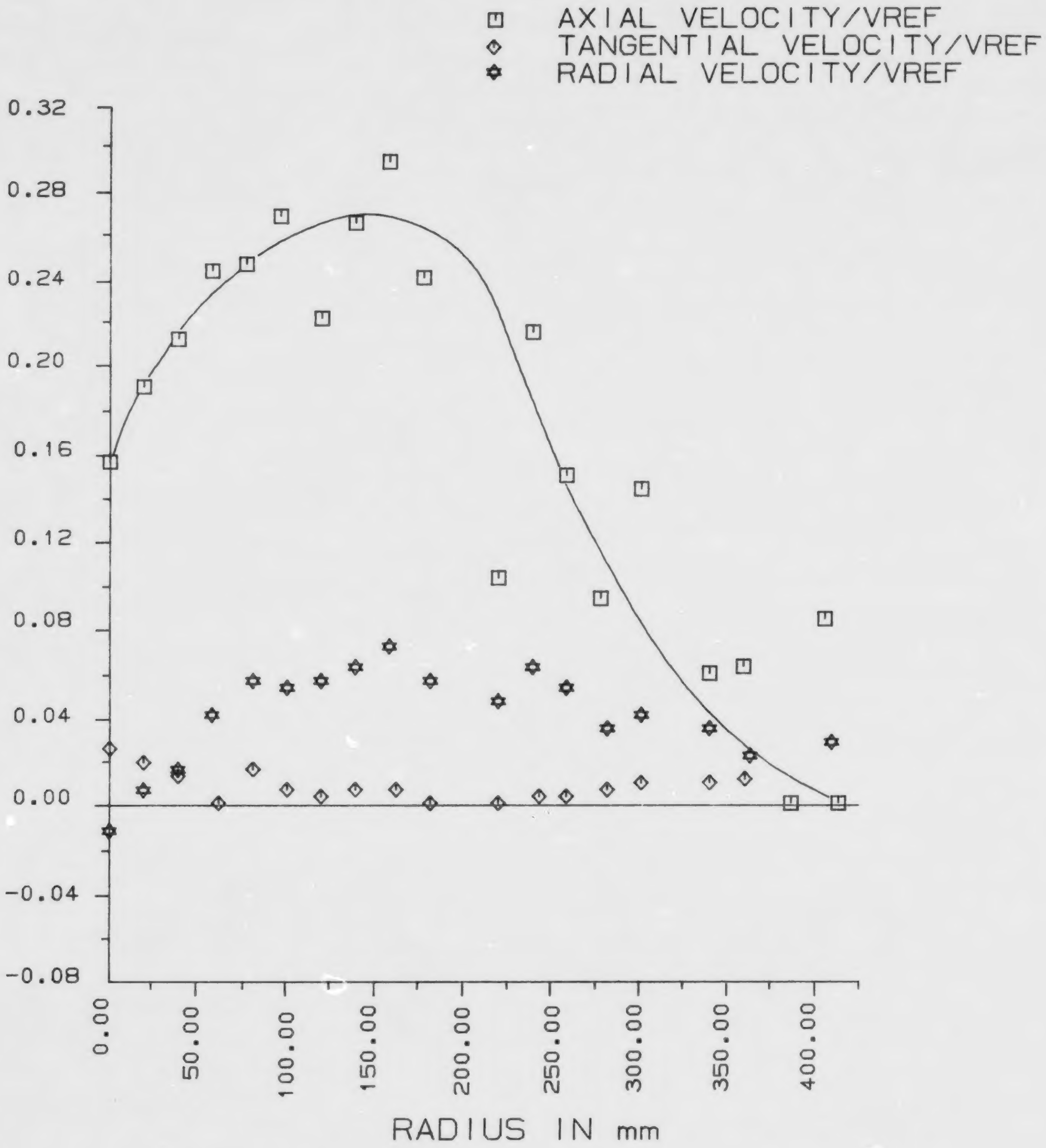


Fig. A1-30 - Velocity profiles at the third tunnel port
(high flow rate, swirl setting 0.0)

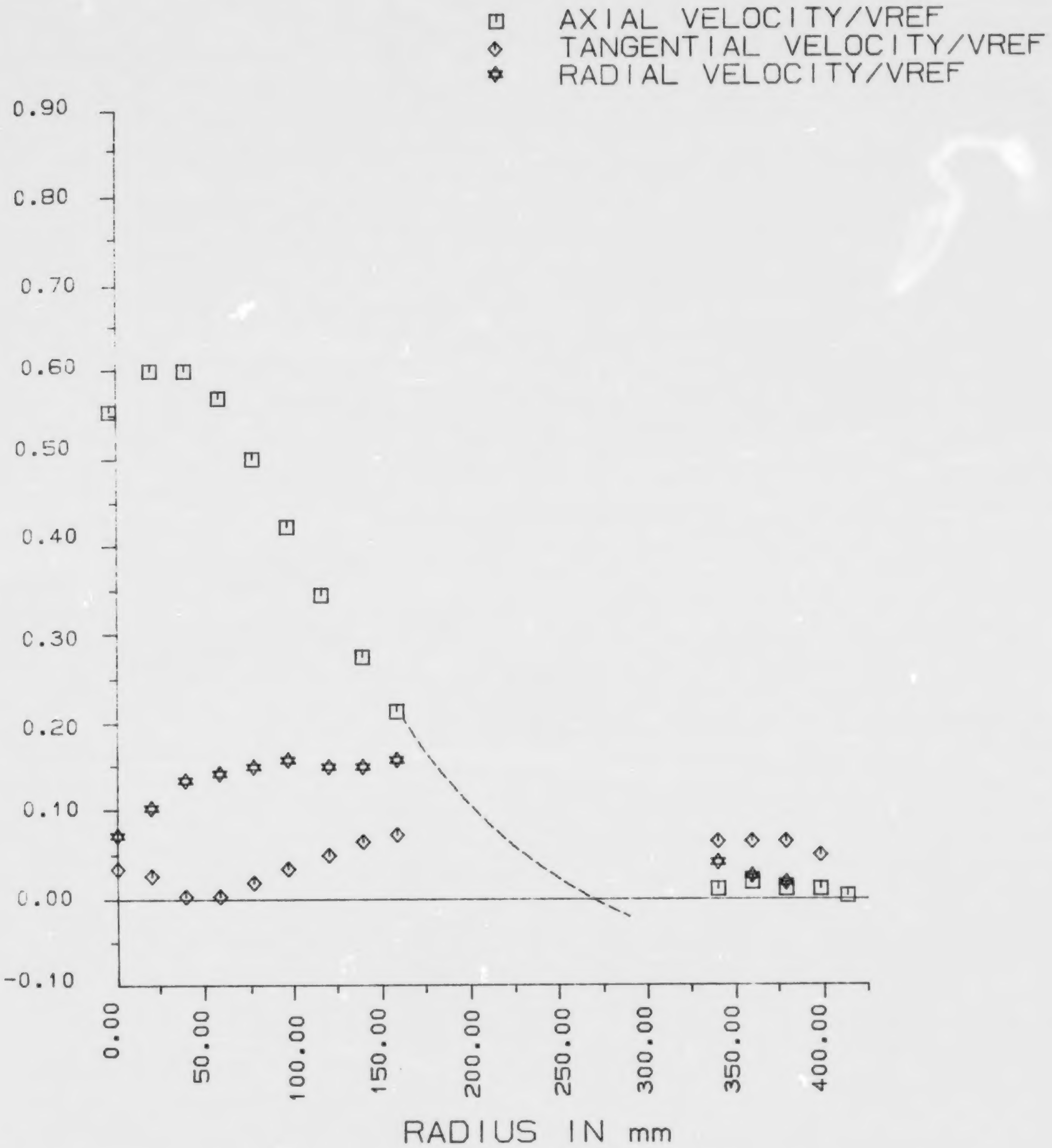


Fig. A1-31 - Velocity profiles at the first tunnel port (high flow rate, swirl setting 0.5)

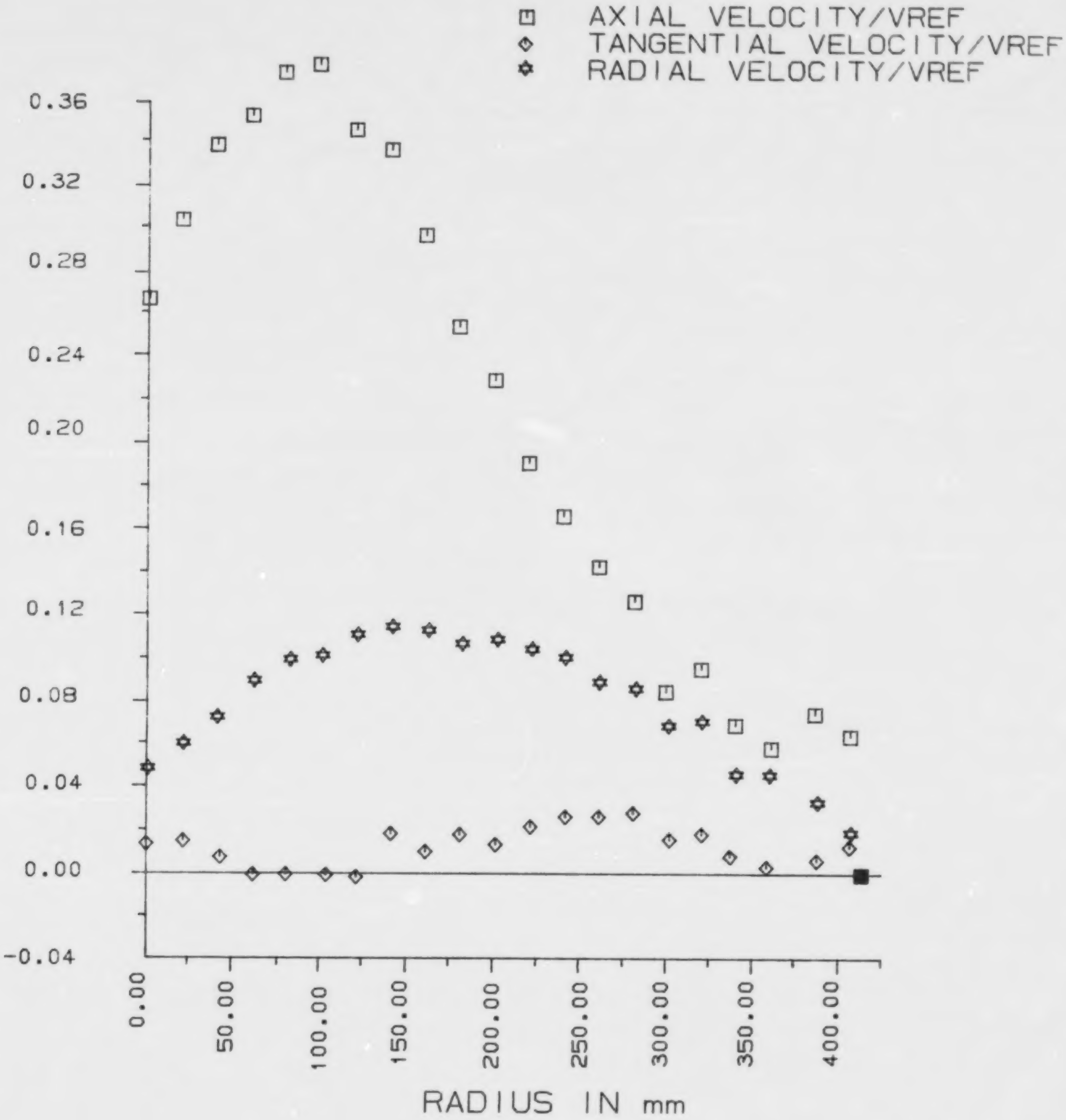


Fig. A1-32 - Velocity profiles at the second tunnel port (high flow rate, swirl setting 0.5)

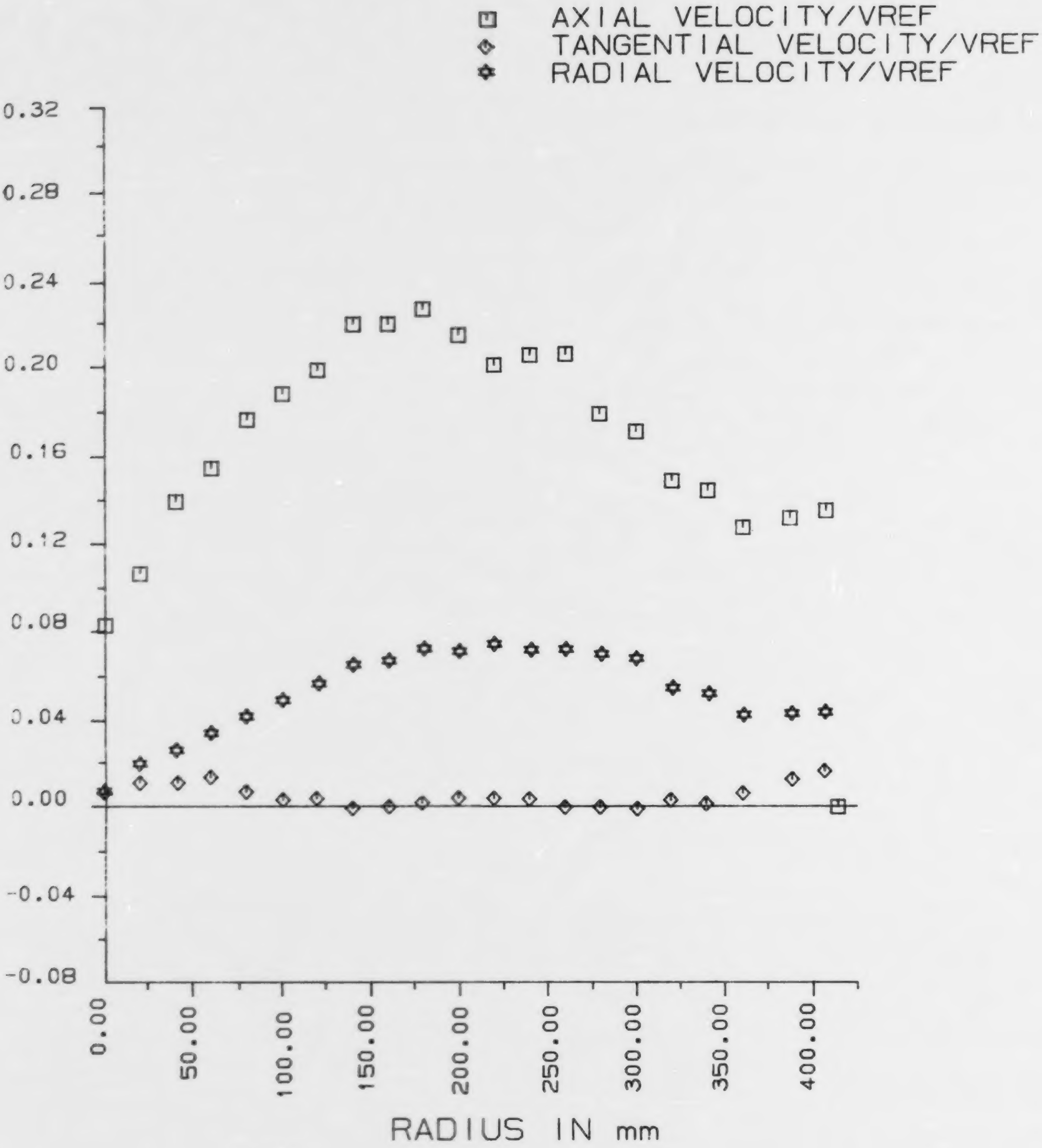


Fig. A1-33 - Velocity profiles at the third tunnel port (high flow rate, swirl setting 0.5)

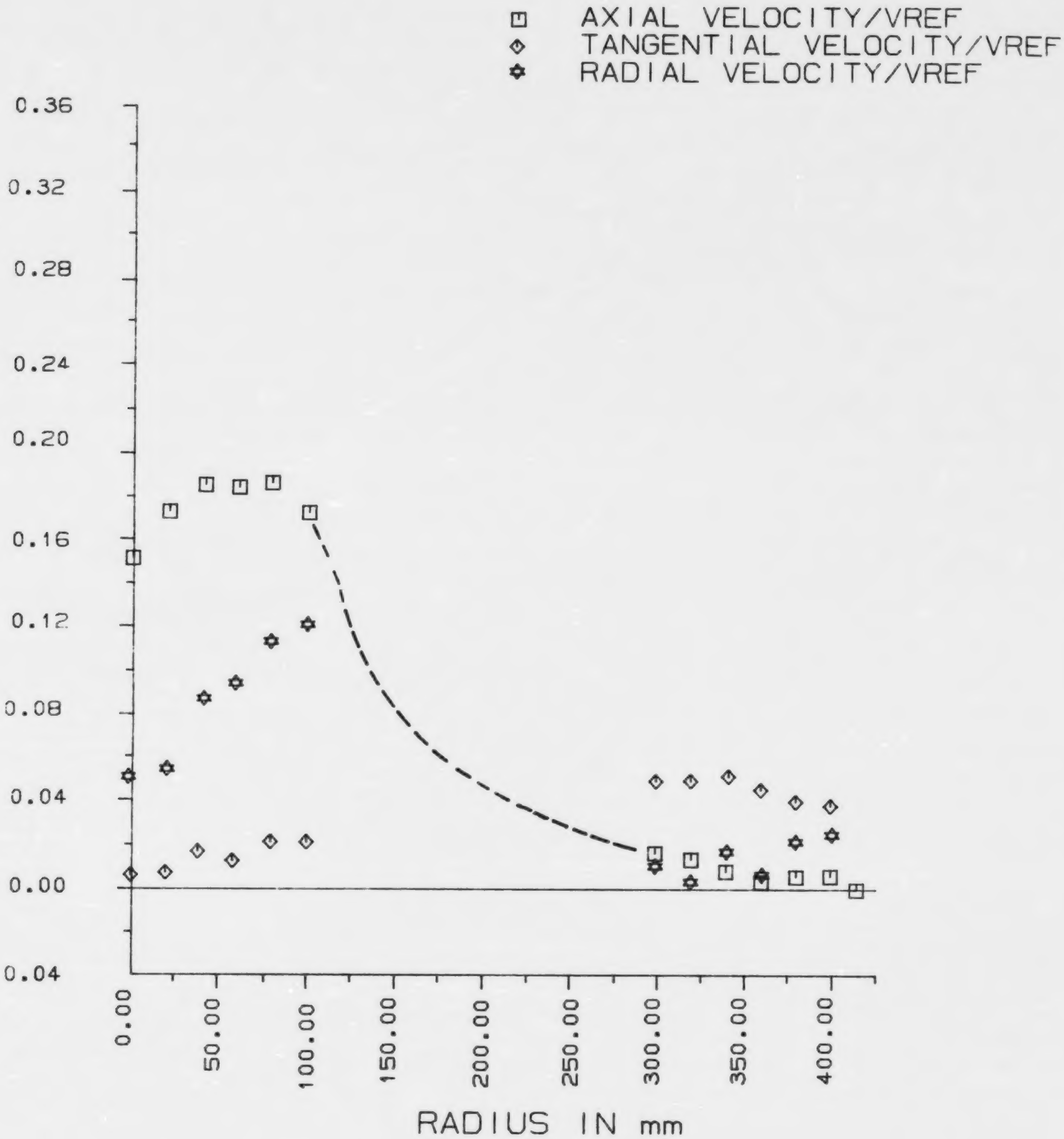


Fig. A1-34 - Velocity profiles at the first tunnel port (high flow rate, swirl setting 1.0)

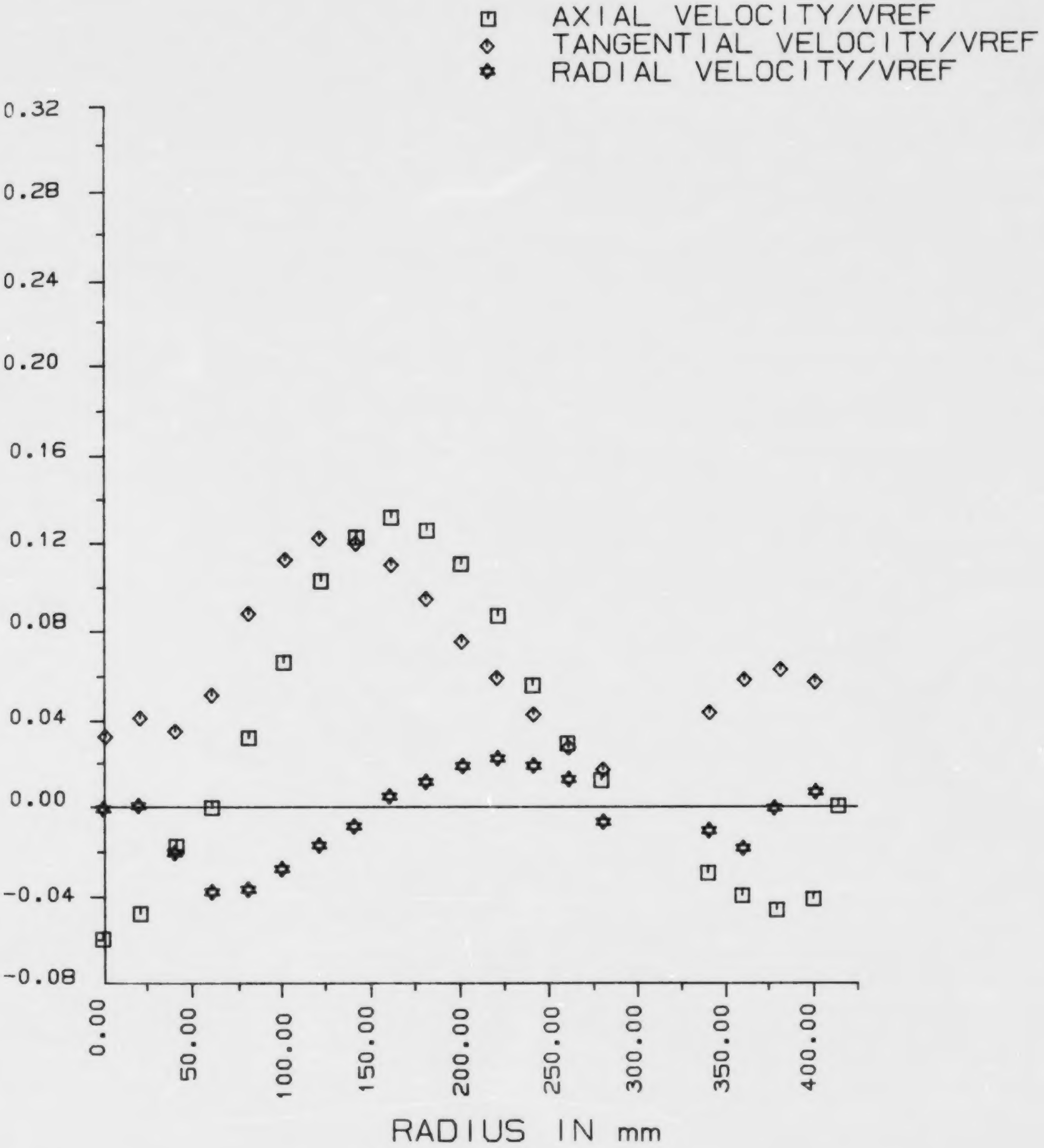


Fig. A1-35 - Velocity profiles at the first tunnel port (high flow rate, swirl setting 2.0)

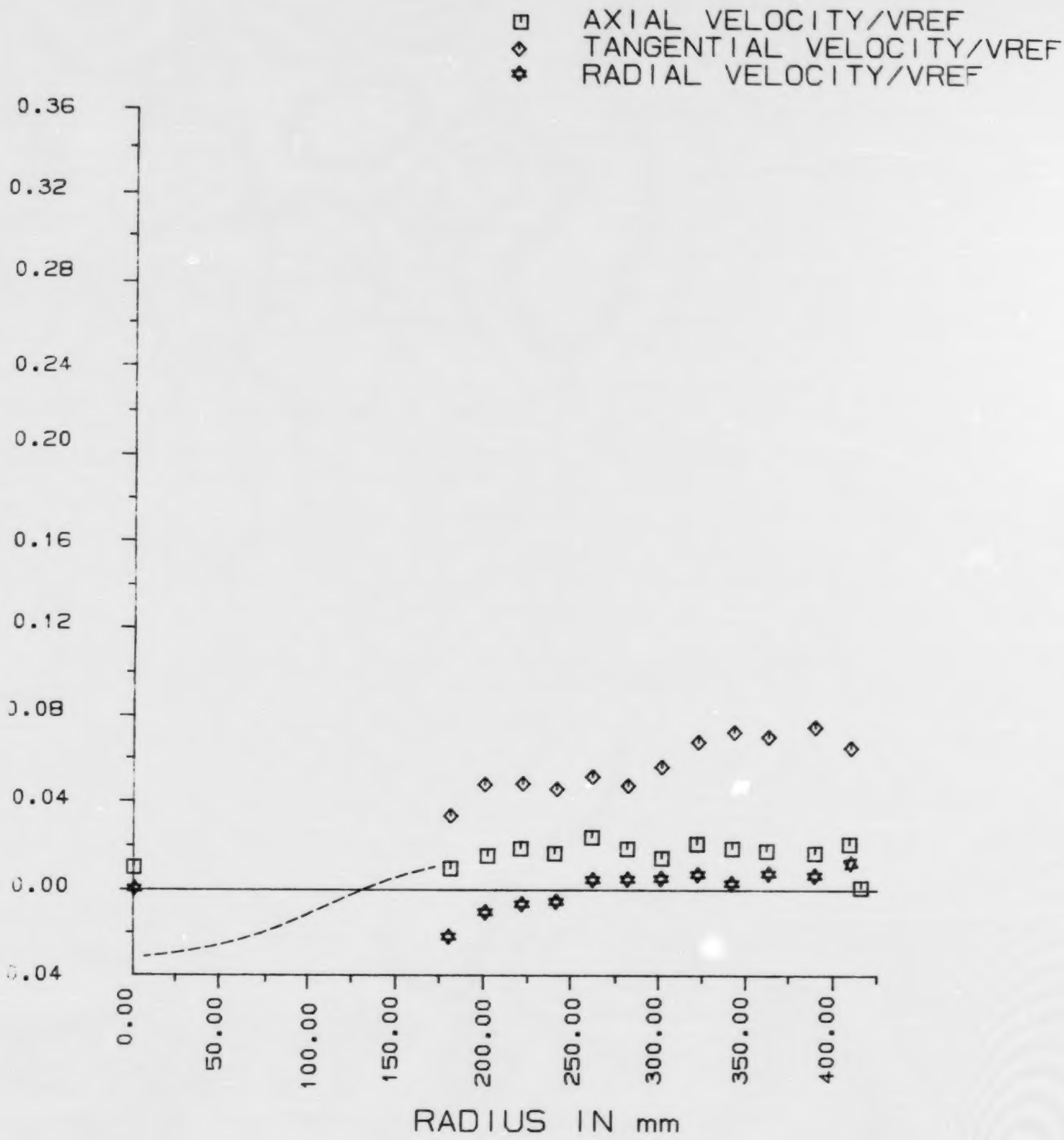


Fig. A1-36 - Velocity profiles at the second tunnel port (high flow rate, swirl setting 2.0)

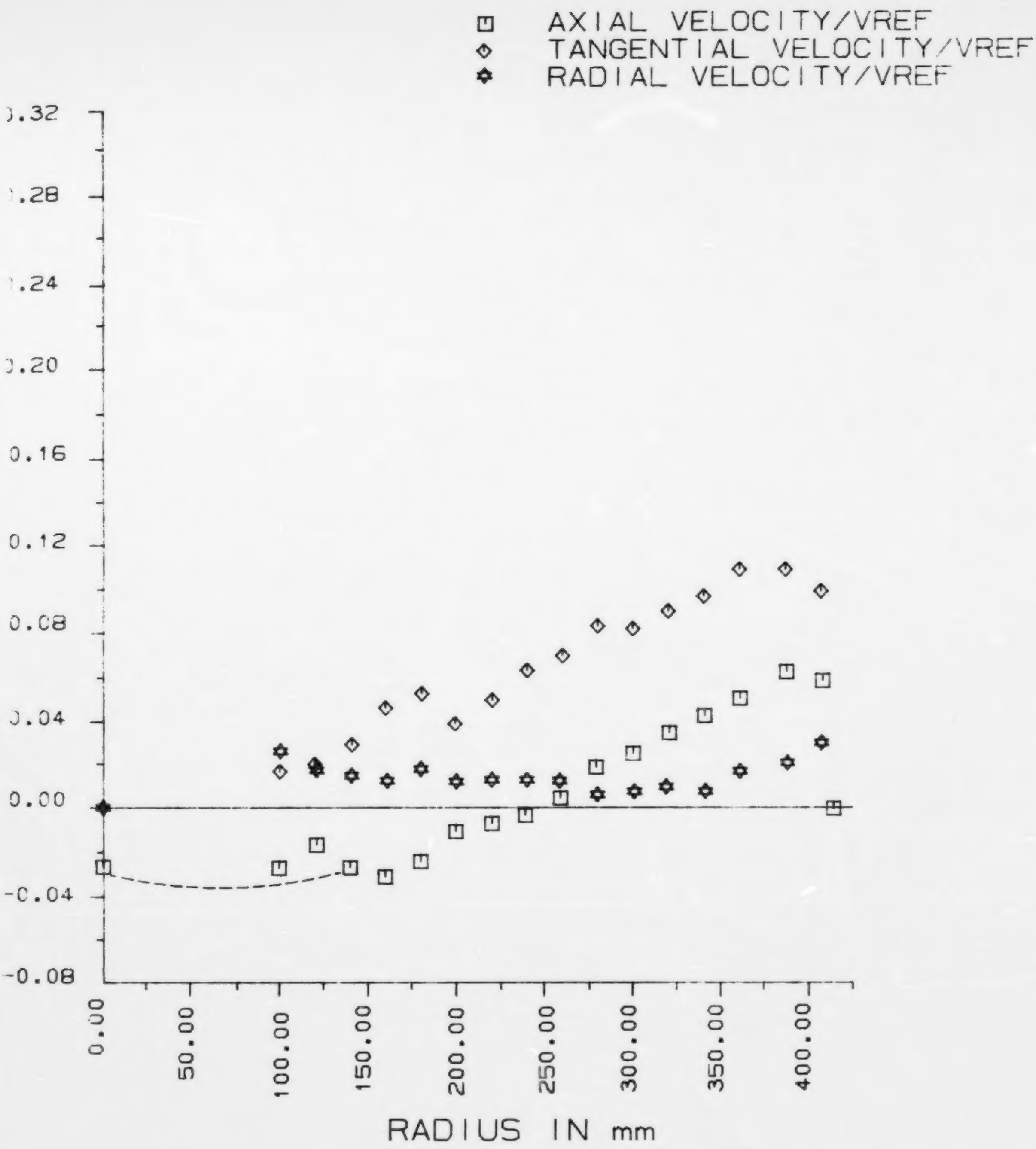


Fig. A1-37 - Velocity profiles at the third tunnel port (high flow rate, swirl setting 2.0)

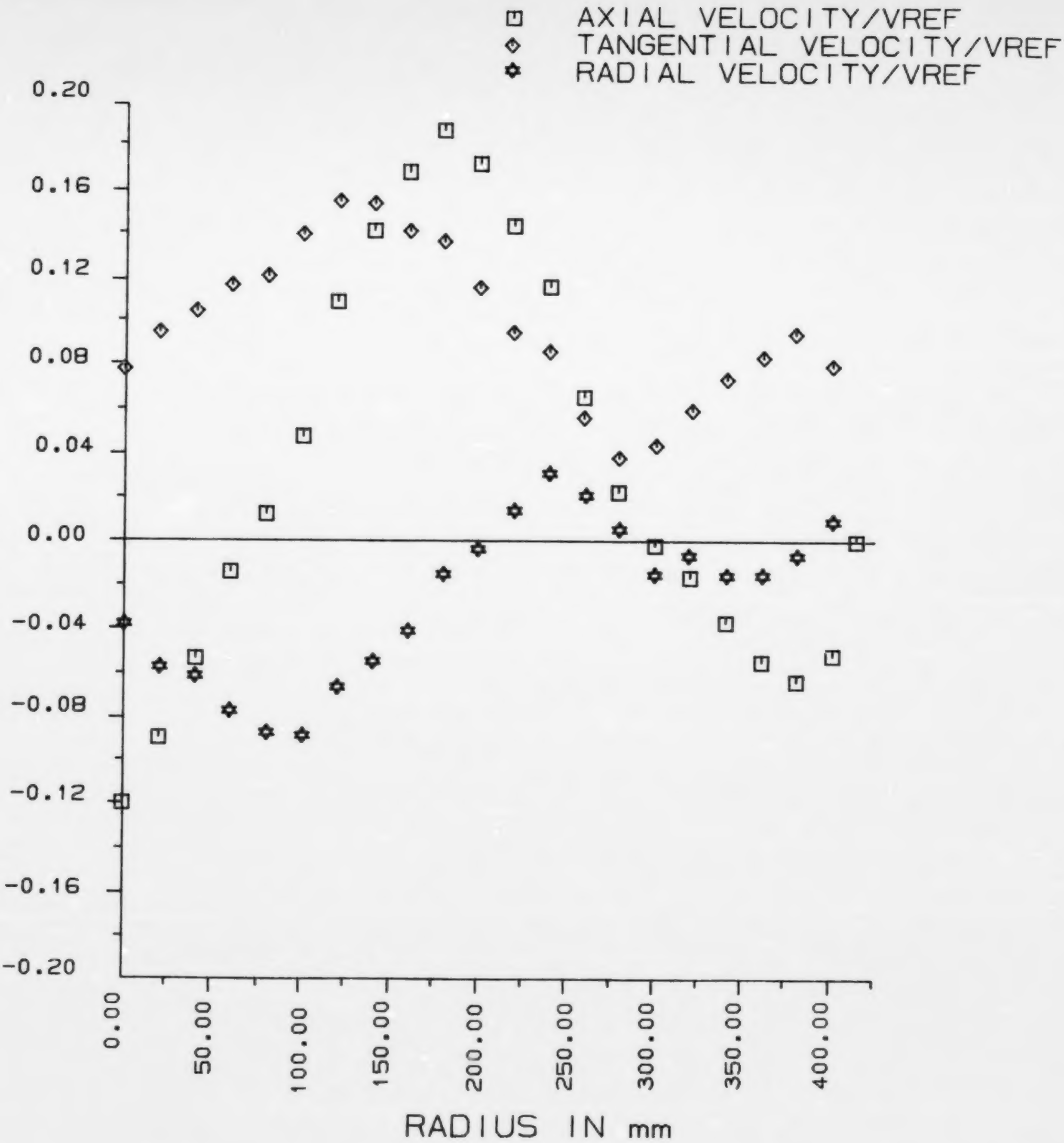


Fig. A1-38 - Velocity profiles at the first tunnel port (high flow rate, swirl setting 3.0)

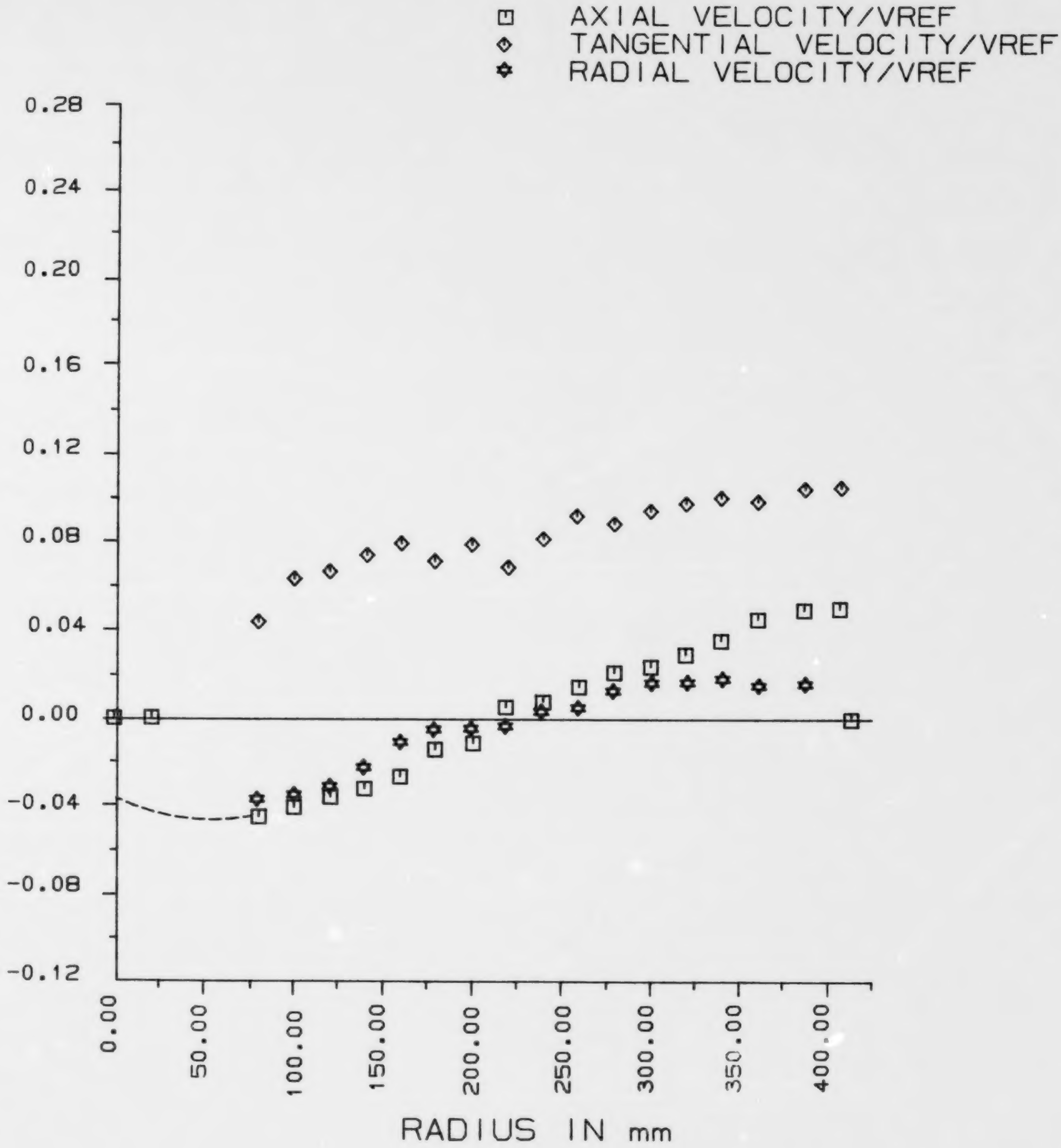


Fig. A1-39 - Velocity profiles at the second tunnel port (high flow rate, swirl setting 3.0)

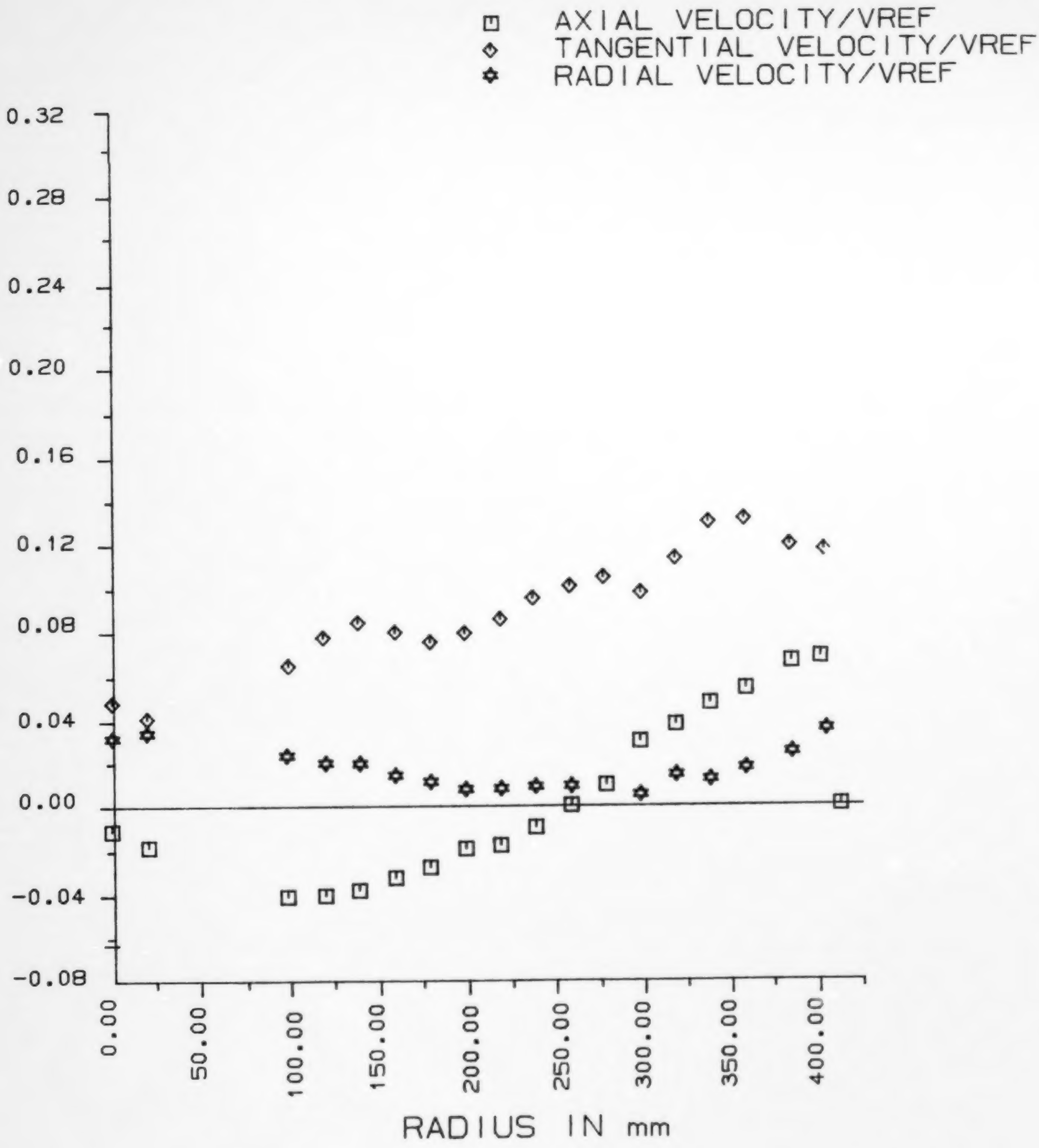


Fig. A1-40 - Velocity profiles at the third tunnel port (high flow rate, swirl setting 3.0)

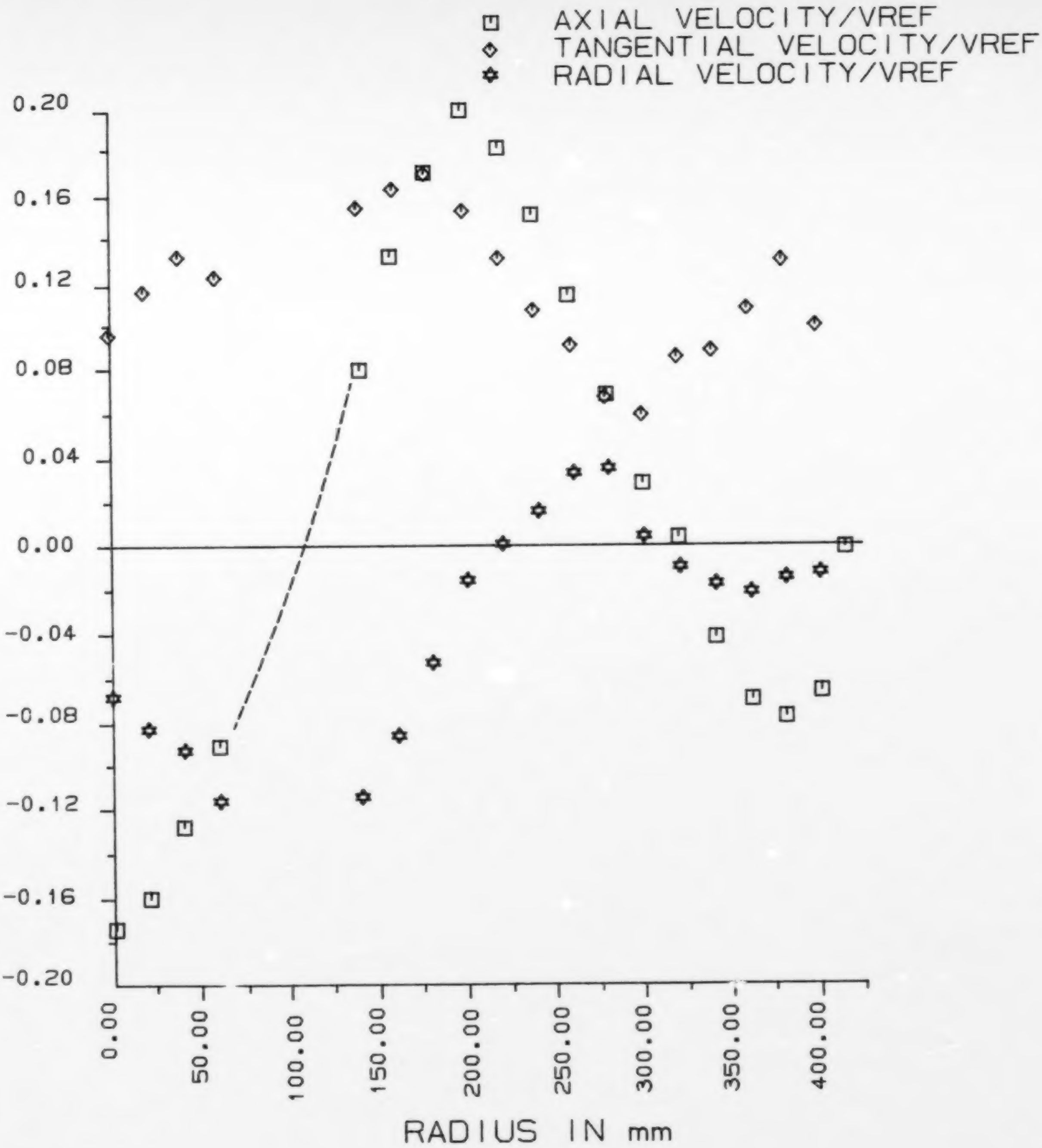


Fig. A1-41 - Velocity profiles at the first tunnel port (high flow rate, swirl setting 4.0)

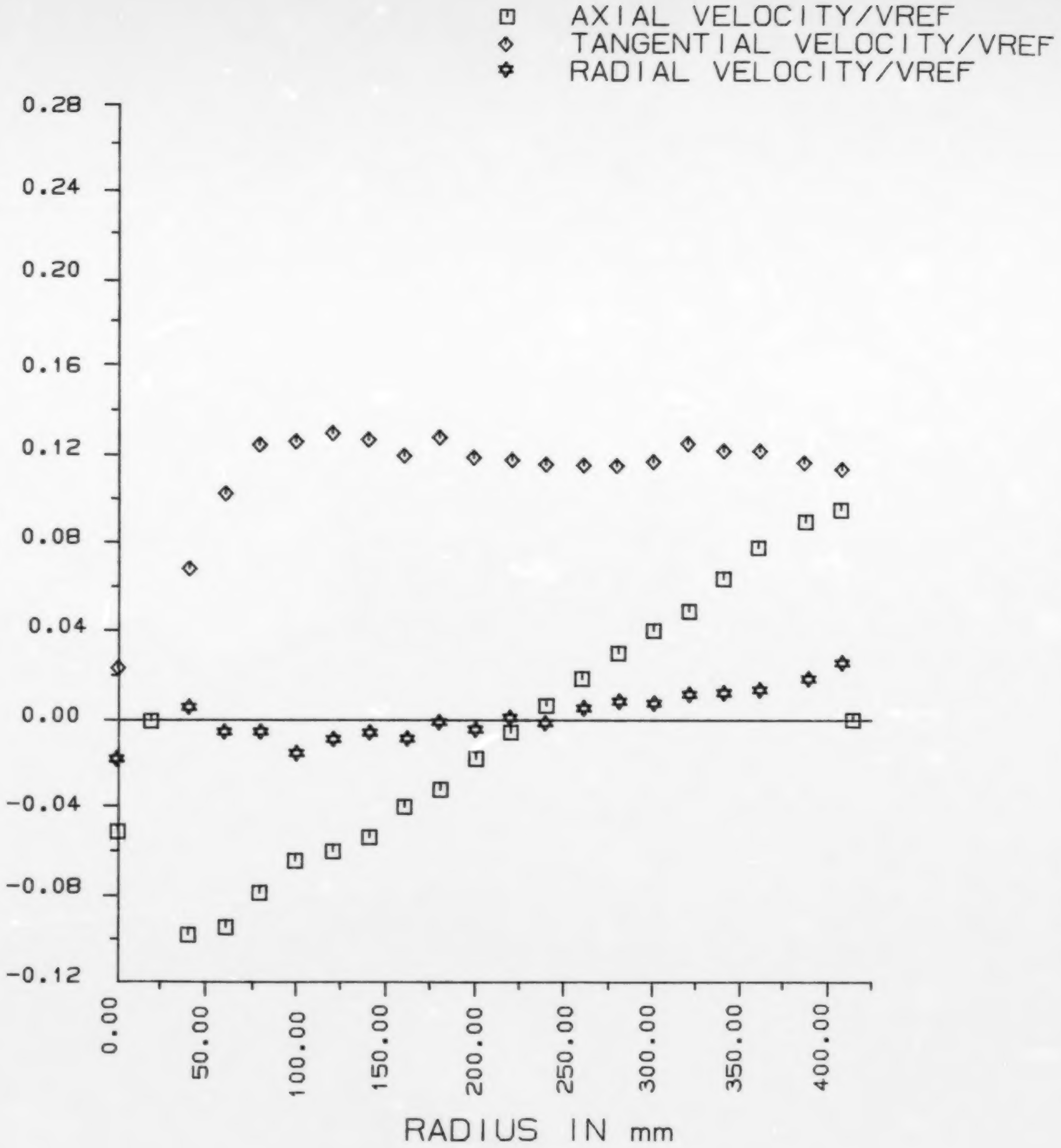


Fig. A1-42 - Velocity profiles at the second tunnel port (high flow rate, swirl setting 4.0)

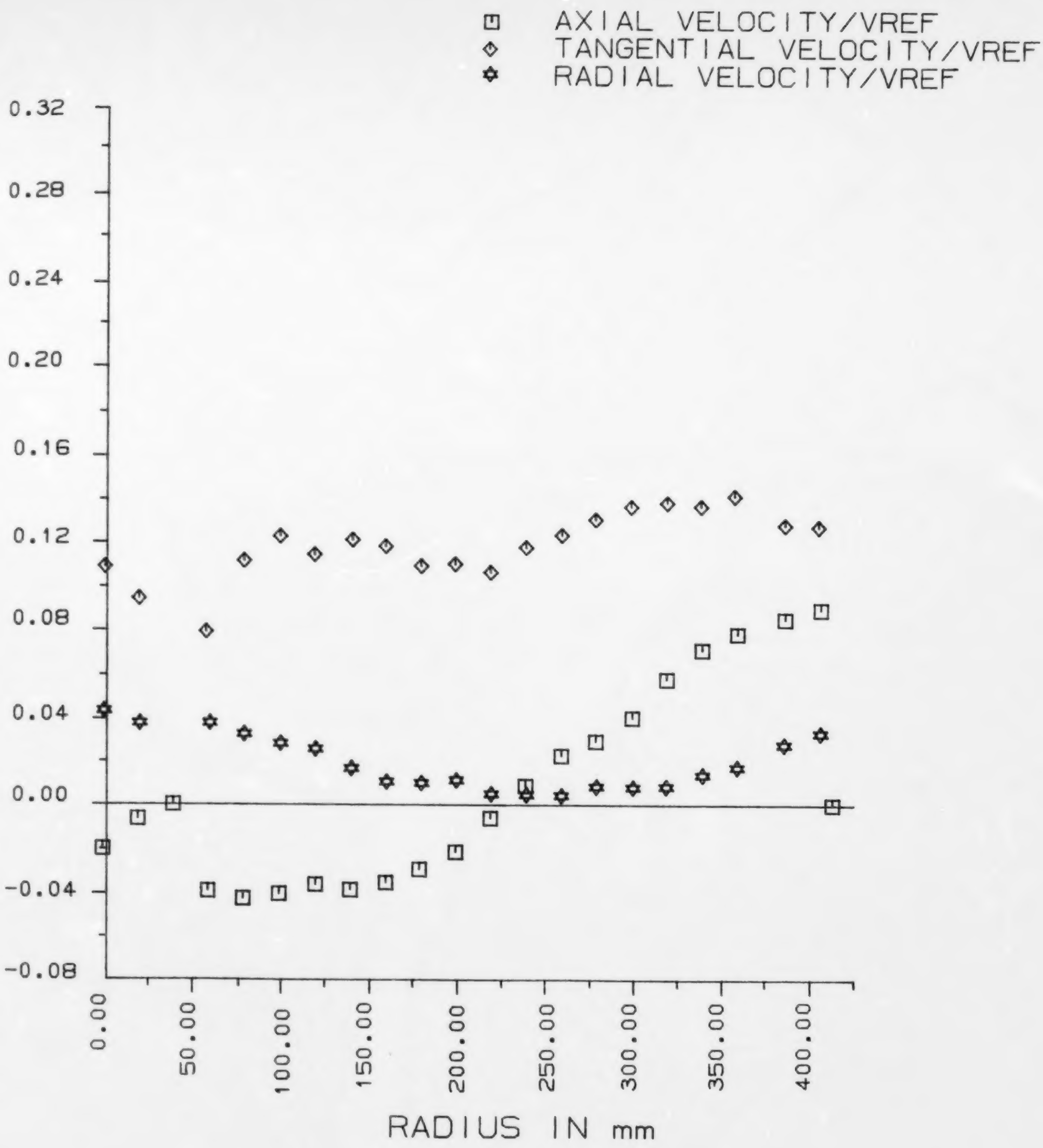


Fig. A1-43 - Velocity profiles at the third tunnel port (high flow rate, swirl setting 4.0)

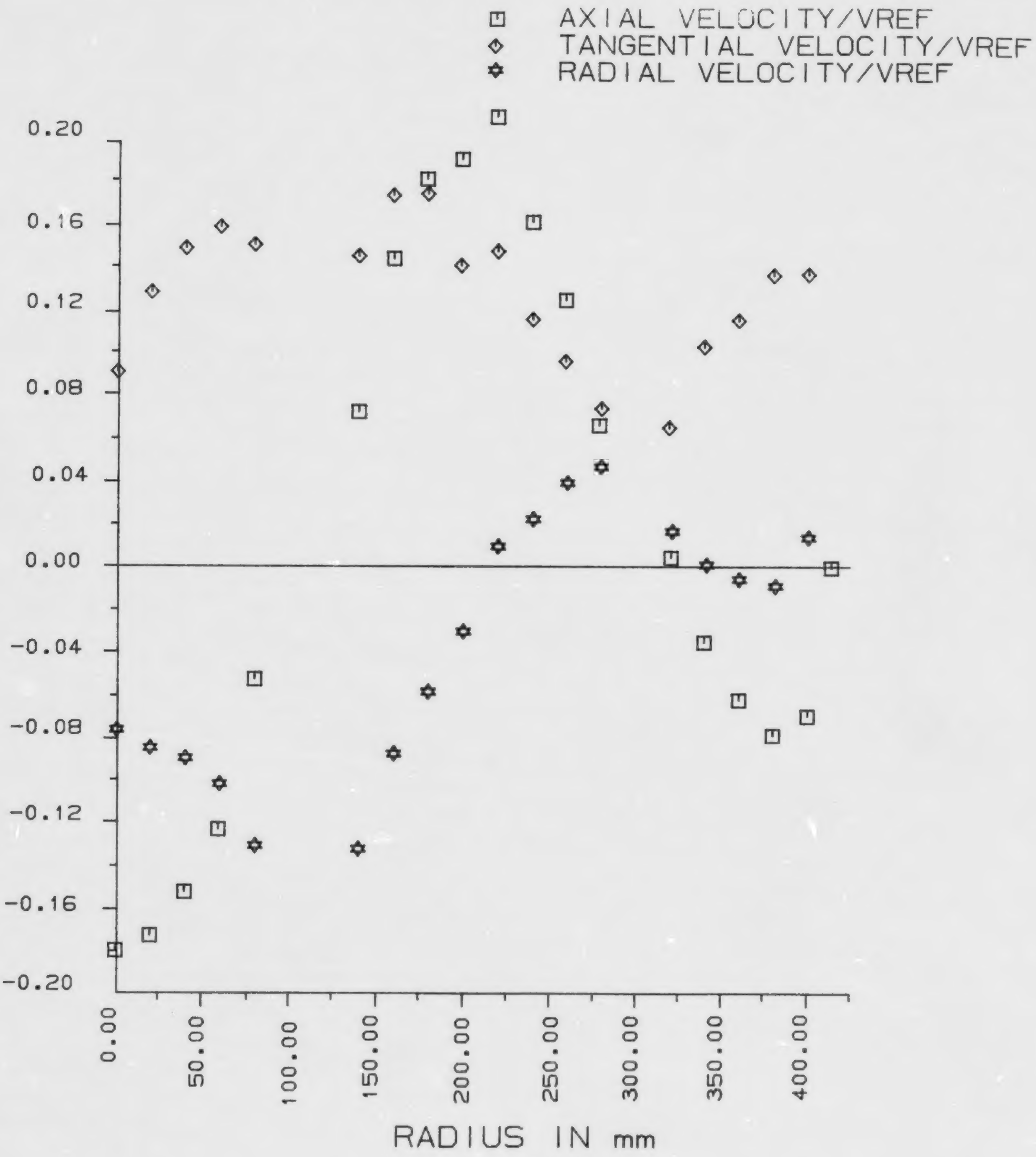


Fig. A1-44 - Velocity profiles at the first tunnel port (high flow rate, swirl setting 4.5)

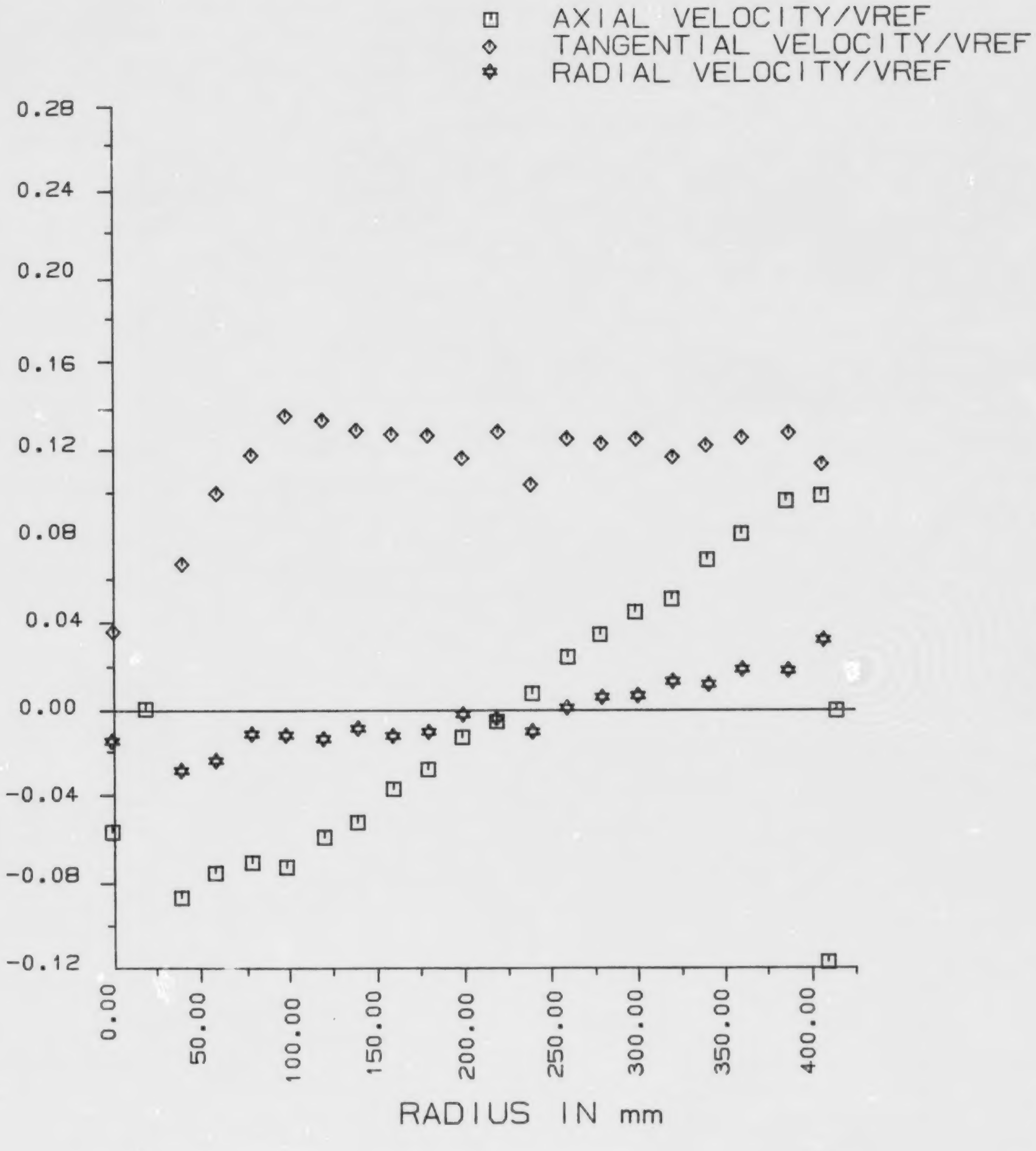


Fig. A1-45 - Velocity profiles at the second tunnel port (high flow rate, swirl setting 4.5)

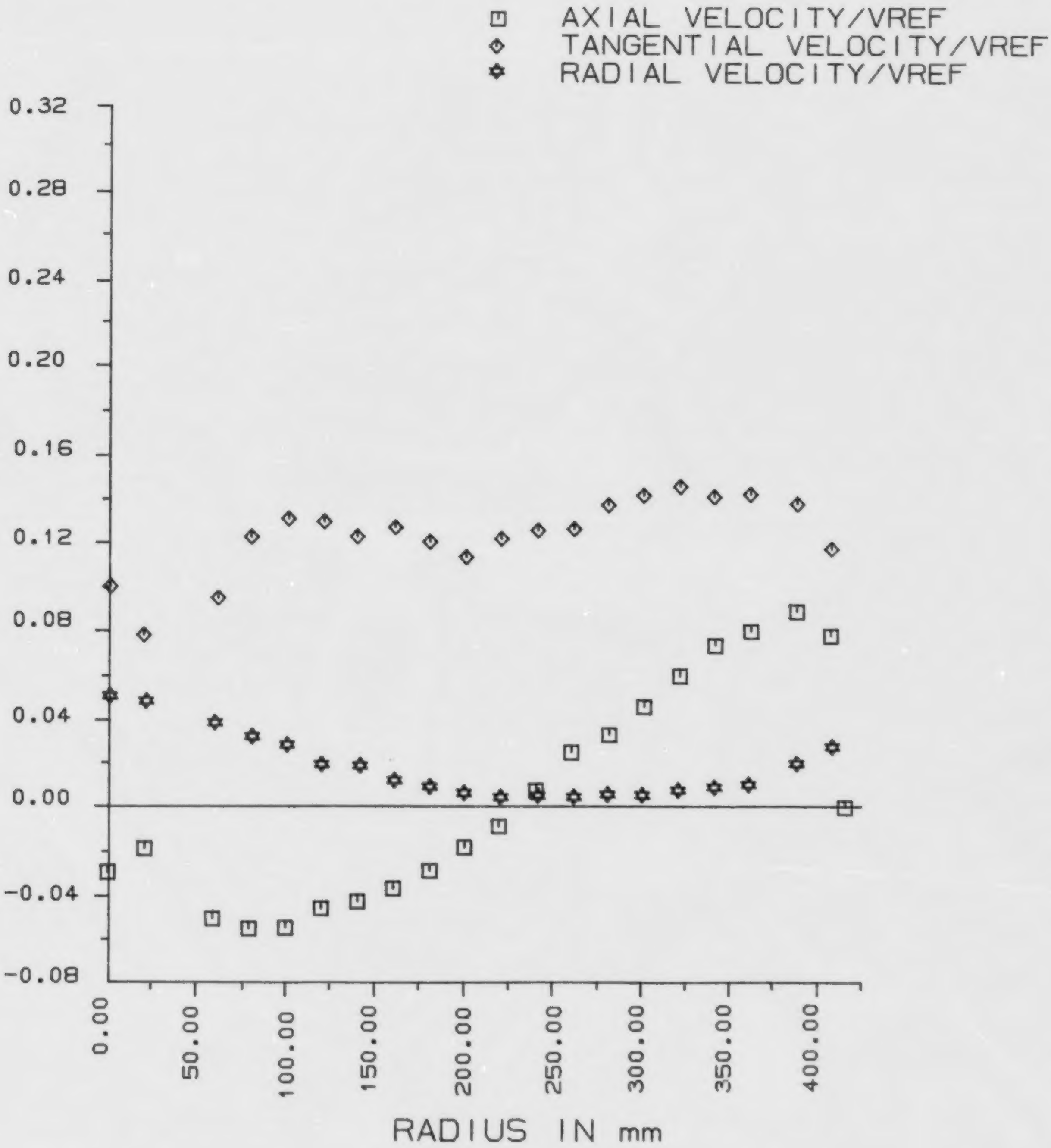


Fig. A1-46 - Velocity profiles at the third tunnel port (high flow rate, swirl setting 4.5)

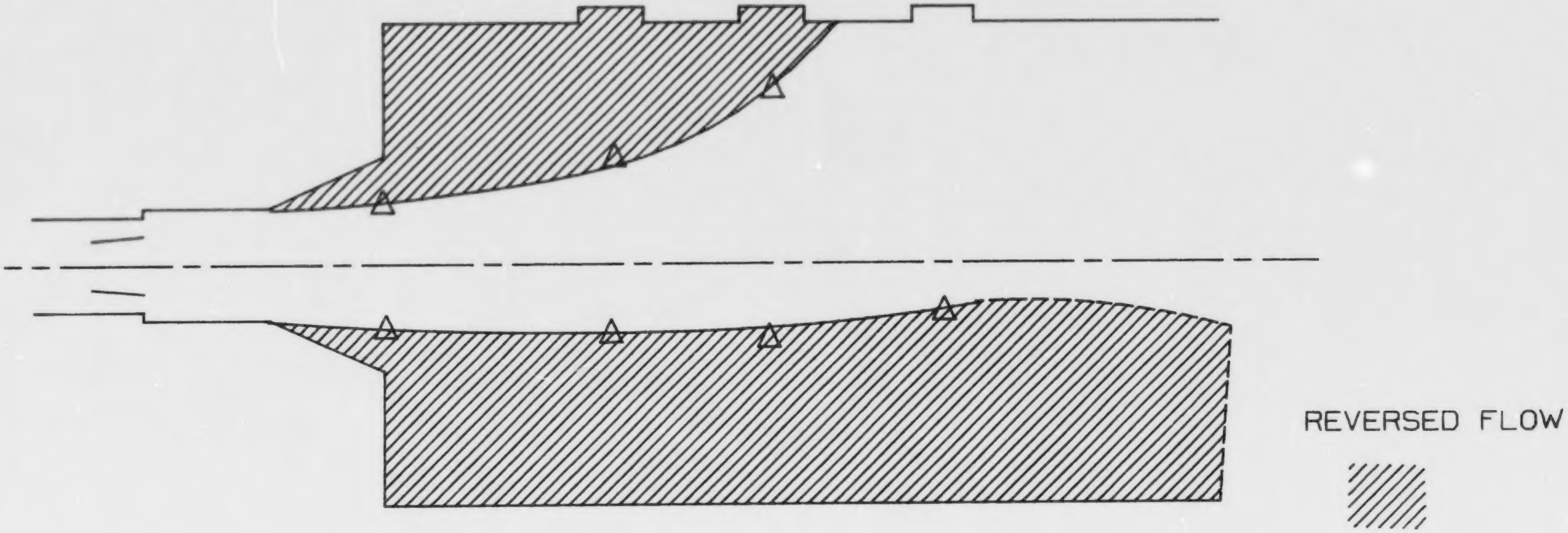

REVERSED FLOW
▨

Fig. A1-47 - Location of backflow region boundaries, swirl setting 0.0

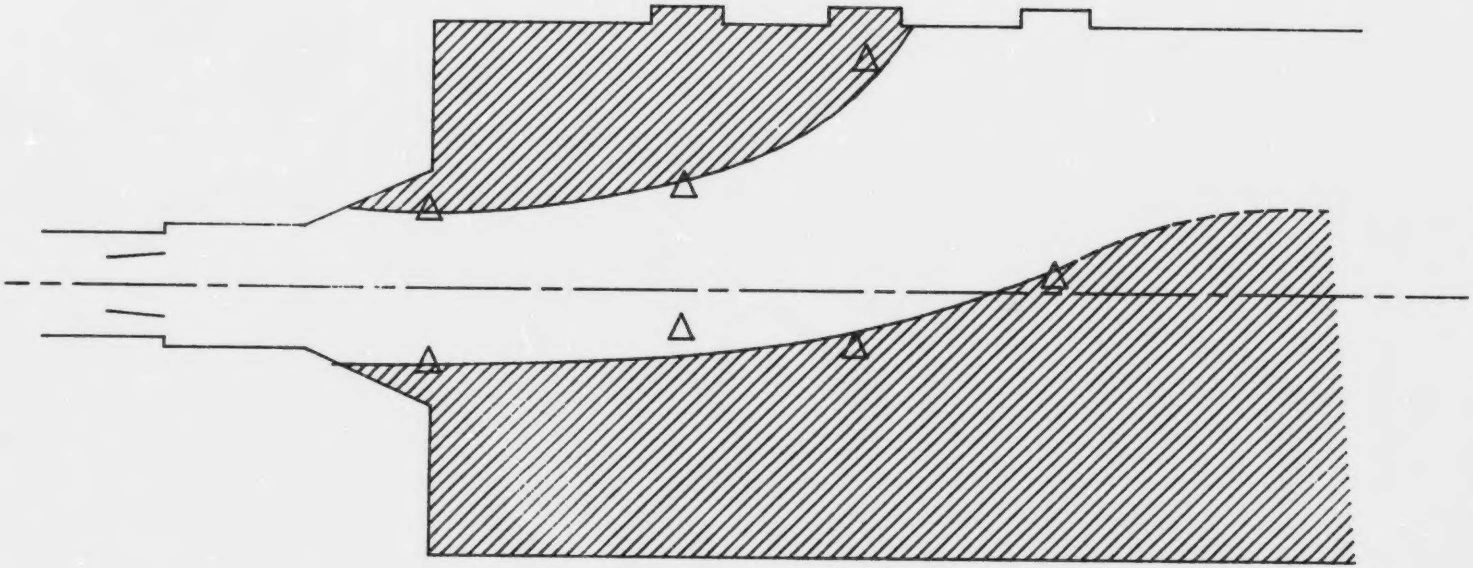


Fig. A1-48 - Location of backflow region boundaries, swirl setting 0.5

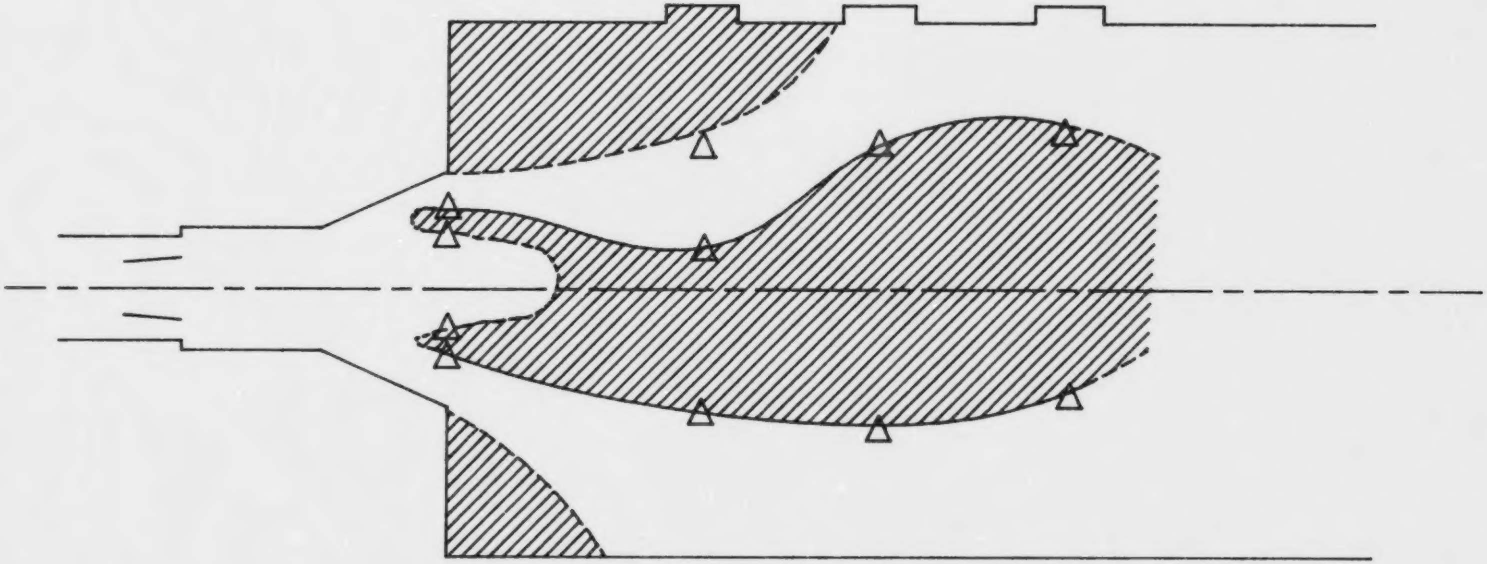


Fig. A1-49 - Location of backflow region boundaries,
swirl setting 2.0

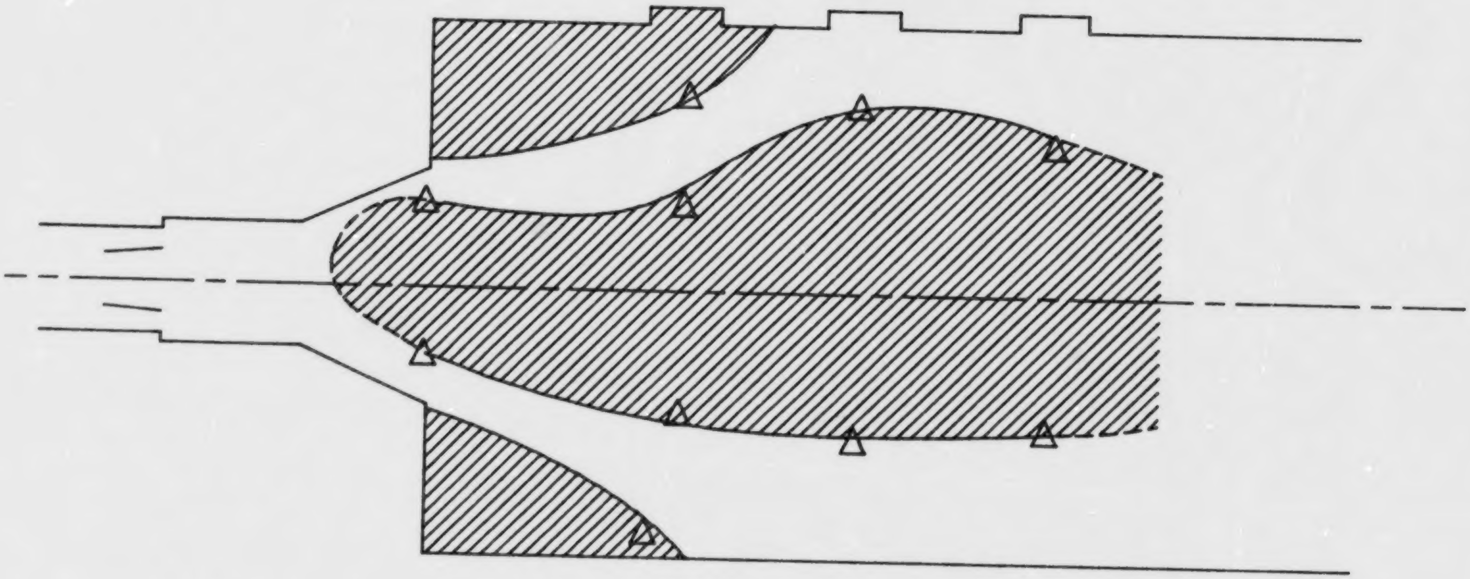


Fig. A1-50 - Location of backflow region boundaries, swirl setting 3.0

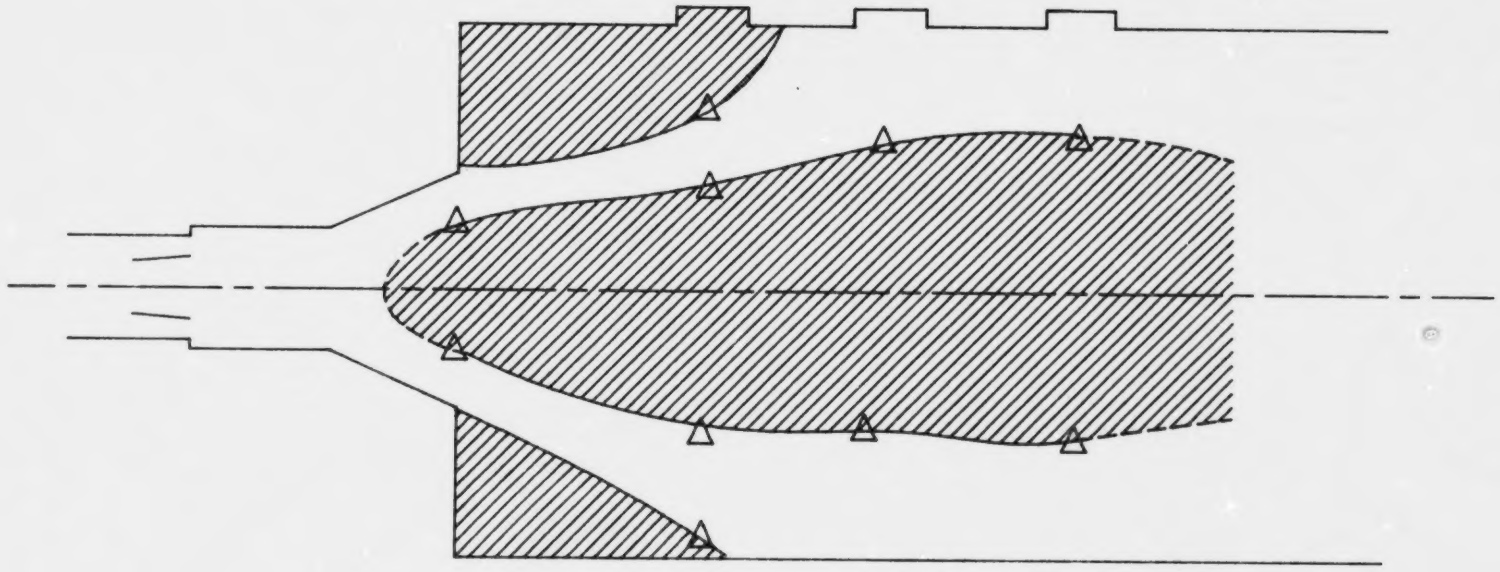


Fig. A1-51 - Location of backflow region boundaries, swirl setting 4.0

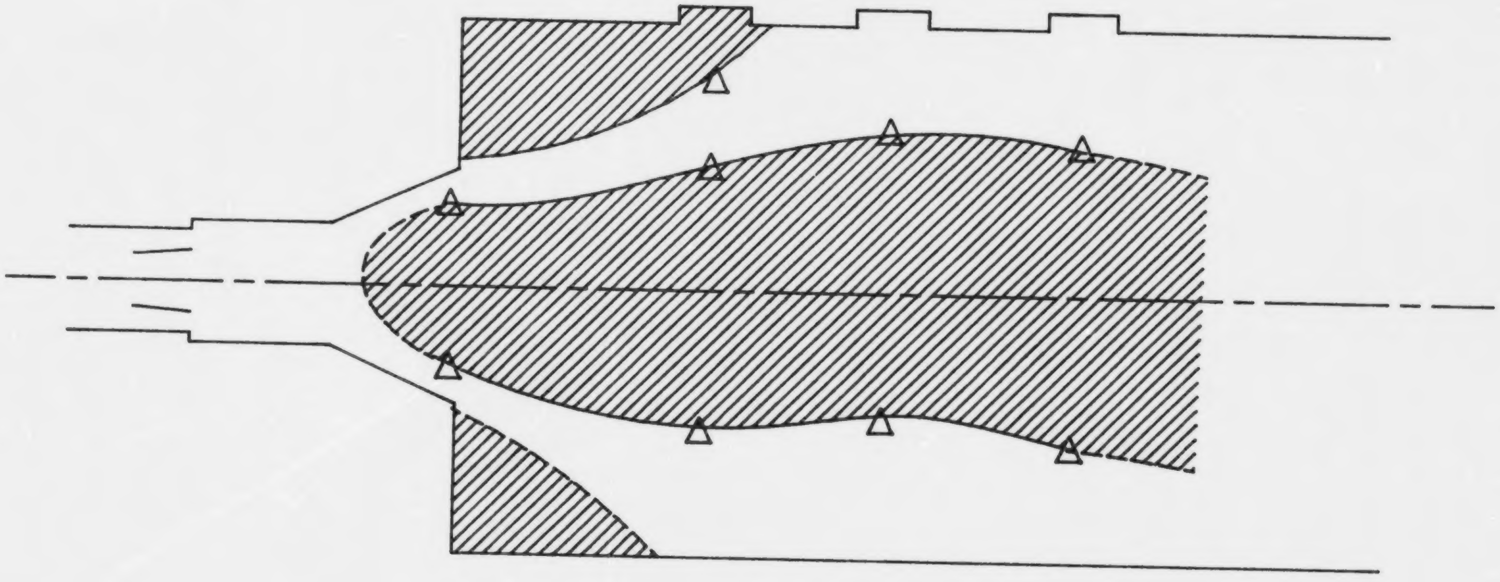


Fig. A1-52 - Location of backflow region boundaries,
swirl setting 4.5

APPENDIX 2

FUEL CHARACTERISTICS AND RUN CONDITIONS

APPENDIX 2

FUEL CHARACTERISTICS AND RUN CONDITIONS

FUEL CHARACTERISTICS

There were three coals used in the combustion experiments: one high-volatile and two low-volatile coals. Number 2 fuel oil was also used for comparison. This Appendix discusses the combustion characteristics of the various fuels used in the combustion trials. Reference is made to the code in Table 3 to identify the fuels used for the individual trials.

The fuel oil was used in the combustion trials A and B and has the following analysis:

Ultimate analysis:

	Wt %
Carbon	86.94
Hydrogen	12.48
Nitrogen	.0214
Sulphur	0.349
Heating value:	45.126 MJ/kg

Other physical characteristics are given as follows:

Specific gravity	0.859
Kinematic viscosity at 37.8°C	2.68 centistokes
Flash point PM	68.5°C

The high-volatile coal (given the code Number 1) was used in the combustion trials C, D, E, H, and I. The analysis of the high-volatile coal is shown in the following list:

Proximate analysis:

	(Wt % dry)
Ash	11.10
Volatiles	34.59
Fixed C	54.31

Ultimate analysis:

	(Wt % dry)
C	68.77
H	3.79
S	0.26
N	0.93
Ash	11.10
O	15.15

Heating value: 26.7 MJ/kg

Two low-volatile coals were used in the combustion studies. One of these (given the code Number 2) was used in combustion trials F and G. The analysis of this coal is given as follows:

Proximate analysis:

	(Wt % dry)
Ash	15.52
Volatiles	21.32
Fixed C	63.16

Ultimate analysis:

	(Wt % dry)
C	73.60
H	3.92
S	0.28
N	1.20
Ash	15.52
O	5.48

Heating value: 29.12 MJ/kg

The combustion studies J and K used the low-volatile coal (given the code Number 3) with the following combustion characteristics:

Proximate analysis:

	(Wt % dry)
Ash	12.61
Volatiles	24.18
Fixed C	63.21

Ultimate analysis:

	(Wt % dry)
C	77.01
H	4.01
S	0.32
N	1.27
Ash	12.61
O	4.78

Heating value: 30.67 MJ/kg

The particle size breakdown of the coal as burned is given for each individual combustion trial since the coal was ground as needed and, as such, may have varied from trial to trial.

RUNNING CONDITIONS FOR COMBUSTION TRIALS A-K

This section contains the running conditions for the eleven combustion trials as well as comments on each experiment. These comments consist of pertinent information on the experimental procedures that may separate the individual experiment or set of measurements from the others.

The running conditions are summarized in Table A2-1 for all of the 11 combustion trials. The fuel code refers to the code used in this appendix for the fuel analyses. It should be noted that the swirl setting is not the swirl number. This is the same swirl setting used in the velocity profile measurements. The primary air flowrate is calculated using the secondary air flowrate and the excess oxygen measurements. The excess oxygen is measured after the last cooling ring. The visible flame length is not available for combustion trials D and H.

Table A2-1 - Run conditions

Trial No.	A	B	C	D	E	F	G	H	I	J	K
Fuel code number	Fuel Oil	Fuel Oil	1	1	1	2	2	1	1	3	3
Firing rate kg/h	30.35	31.20	50.64	50.50	53.80	61.60	57.0	59.7	61.2	60.0	59.8
Burner configuration	Fig. 2	Fig. 2	Fig. 2	Fig. 2	Fig. 2	Fig. 3a	Fig. 3a	Fig. 3b	Fig. 3b	Fig. 3b	Fig. 3b
Swirl setting	0	3	0.0	3.0	1.0	3.0	4.5	3.0	4.5	3.0	4.5
Primary air temp °C	75.58	74.60	99.99	89.7	84.0	96.0	94.0	98.0	88.0	93.0	86.0
Primary air flow kg/h	278.11	299.84	347.66	368.63	431.99	313.92	403.02	458.38	487.94	502.11	411.87
Second air temp °C	22.94	25.50	122.53	116.5	122.0	136.0	153.0	138.0	135.0	122.0	140.0
Second air flow kg/h	309.04	292.94	187.76	184.77	179.89	574.45	424.93	342.06	320.54	180.72	295.1
Nominal excess oxygen vol %	5.0	4.9	5.0	5.0	5.0	8.0	8.0	8.0	8.0	3.0	3.0
Visible flame length m	n.a.	n.a.	1.4	n.a.	1.2	2.1	2.2	n.a.	1.3	2.2	1.5
Combustibles in fly ash wt %	n.a.	n.a.	6.93	2.70	4.35	26.65	29.14	0.97	0.5	50.4	28.2

NOTES ON THE COMBUSTION TRIALS

For each of the combustion experiments, there were subtle differences in the running conditions and measurement techniques. These differences range from the particle size distribution of the fuel to the location of the furnace draft measurement. These minor differences may affect the comparison of one combustion trial to another.

No notes were kept for Trials A and B. The nozzle (10.5 GpH-30° HV) used for both trials gave a 30° cone spray. No measurements were made concerning the spray pattern.

COMBUSTION TRIAL C

As indicated in Table A2-1, the fuel used for this combustion trial was the high-volatile coal code number 1. The particle size distribution of the pulverized fuel as burned is given in the following list:

Mesh size	Wt %
+60	0.0
-60 +100	0.0
-100 +140	3.5
-140 +200	6.1
-200 +325	75.9
-325 +400	6.1
-400	8.4

For this combustion trial there is no breakdown of the fines.

The flame quality was judged to be good for this combustion trial. The furnace was maintained under a slightly positive pressure for all of the combustion trials. The location of the draft measurement for this experiment was well into the exhaust stack far away from the furnace interior. Since an induced draft fan was used, the static pressure as measured at this location was lower than that measured in the furnace. Thus, when a desired pressure was set according to this measurement, the pressure in the furnace was higher than desired. As a result, the combustion gases exited through the sample ports, at a much higher rate than expected. Because the hot combustion gases flowed through the sample ports, the total heat flux measurements are expected to be higher than reality. There may also be some flame radiation measurements missing since the gases flowing through the sample ports posed a hazard to the measurement device and to the technician. The radiation measurements taken, however, are not expected to be in error because a purge gas flowed through the entrance to the ellipsoidal cavity of the radiometer and, as such, prevented any measurement bias. For this combustion trial, the pipe feeding the primary air and coal to the burner from the pulverizer was 8.89 cm in diameter. This size of pipe was chosen to maintain the appropriate pressure in the pulverizer.

COMBUSTION TRIAL D

As indicated in Table A2-1, the fuel used for this combustion trial was the high-volatile coal code number 1. The particle size distribution of the pulverized fuel as burned is given in the following analysis:

Mesh size	Wt %
+60	0.0
-60 +100	0.3
-100 +140	1.9
-140 +200	6.5
-200 +325	74.2
-325 +400	6.9
-400	10.2

For this combustion trial there is no breakdown of the fines.

The discussion of the conditions of the combustion trial is the same as that given for combustion Trial C.

COMBUSTION TRIAL E

As indicated in Table A2-1, the fuel used for this combustion trial was the high-volatile coal code number 1. The particle size distribution of the pulverized fuel as burned is given in the following list:

Mesh size	Wt %
+60	0.0
-60 +100	0.3
-100 +140	4.0
-140 +200	8.0
-200 +325	71.4
-325 +400	6.9
-400	9.4

For this combustion trial there is no breakdown of the fines.

The discussion of the conditions for this combustion trial is the same as that for combustion Trial C. The flame, as viewed from the end, had a tendency to lean towards the side of the furnace opposite to the sample ports and upward. It should also be noted that the temperature measurements within the first metre of the furnace using the suction pyrometer had to be terminated since this posed a hazard to the probe and tended to disturb the flow of gases. This practice was continued for Trials E to K.

COMBUSTION TRIAL F

As indicated in Table A2-1, the fuel used for this combustion trial was the low-volatile coal code number 2. The particle size distribution of the pulverized fuel as burned is given in the following list:

Mesh size	Wt %
+100	1.0
-100 +140	3.0
-140 +200	10.0
-200 +325	62.0
-325 +400	13.0
-400	11.0

For this combustion trial, the breakdown of the fines is shown tabulated in Tables A2-2 and A2-3. Note that for this combustion trial only, the size fractions -400 and -325 to +400 mesh are broken down into the finer sizes. It is shown in these tables (A2-2 and A2-3) that the two size ranges -400 and -325 to +400 mesh do not show a significant difference from the point of view of particle size distribution.

Table A2-2 - Particle size distribution of the as-burned coal for combustion Trial F size range -400 mesh

CH.#	Size (μm)	Diff vol %	Cum vol %	Diff pop %	Cum pop %
1	4.00	.4	100.0	0	100.0
2	5.04	2.2	99.6	23.3	100.0
3	6.35	3.7	97.4	21.0	76.7
4	8.00	6.6	93.7	19.9	55.7
5	10.08	9.0	87.1	13.5	35.8
6	12.70	12.2	78.1	9.9	22.3
7	16.00	15.1	65.9	6.1	12.4
8	20.16	18.0	50.8	3.8	6.3
9	25.40	19.4	32.8	2.0	2.5
10	32.00	8.6	13.4	.5	.5
11	40.32	1.6	4.8	0	0
12	50.80	.5	3.2	0	0
13	64.00	.6	2.7	0	0
14	80.63	.6	2.1	0	0
15	101.59	.6	1.5	0	0
16	128.00	.7	.9	0	0

Table A2-3 - Particle size distribution of the as-burned coal for combustion Trial F size range -325 to +400 mesh

CH.#	Size (μm)	Diff vol %	Cum vol %	Diff pop %	Cum pop %
1	4.00	.6	100.0	0	100.0
2	5.04	2.5	99.4	28.9	100.0
3	6.35	4.0	96.9	23.8	71.1
4	8.00	6.0	92.9	18.9	47.3
5	10.08	7.0	86.9	11.0	28.4
6	12.70	8.6	79.9	7.3	17.4
7	16.00	10.2	71.3	4.3	10.1
8	20.16	13.5	61.1	3.0	5.8
9	25.40	15.1	47.6	1.6	2.8
10	32.00	20.4	32.5	1.1	1.2
11	40.32	8.3	12.1	.2	.1
12	50.80	.7	3.8	0	0
13	64.00	.7	3.1	0	0
14	80.63	.8	2.4	0	0
15	101.59	.8	1.6	0	0
16	128.00	.8	.8	0	0

The discussion giving the conditions for the combustion Trial C applies to this combustion trial also. The sole exception is that the whole of the interior of the furnace glowed red so that the flame length indicated in Table A2-1 is rather subjective. Also, there appeared to be some puffing of the flame probably due to coal collecting on the downstream side of the bluff body and breaking off intermittently.

COMBUSTION TRIAL G

As indicated in Table A2-1, the fuel used for this combustion trial was the low-volatile coal code number 2. The particle size distribution of the pulverized fuel as burned is given in the following analysis:

Mesh size	Wt %
+100	0.3
-100 +140	6.0
-140 +200	9.0
-200 +325	60.0
-325 +400	14.0
-400	11.0

For this combustion trial the breakdown of the fines is shown in Table A2-4.

Table A2-4 - Particle size distribution of the as-burned coal for combustion Trial G size range -400 mesh

CH.#	Size (μm)	Diff vol %	Cum vol %	Dif pop %	Cum pop %
1	4.00	.3	100.0	0.0	100.0
2	5.04	1.1	99.7	14.7	100.0
3	6.35	2.1	98.6	16.7	85.3
4	8.00	4.6	96.5	19.0	68.6
5	10.08	7.6	91.9	16.0	49.6
6	12.70	11.4	84.3	13.2	33.6
7	16.00	16.9	72.9	9.9	20.4
8	20.16	21.7	56.0	6.5	10.5
9	25.40	22.7	34.3	3.4	4.0
10	32.00	8.8	11.6	.7	.6
11	40.32	1.0	2.8	0	0
12	50.80	.5	1.8	0	0
13	64.00	.4	1.3	0	0
14	80.63	.4	.9	0	0
15	101.59	.4	.5	0	0
16	128.00	.4	.1	0	0

The discussion giving the conditions for this combustion trial is the same as that for combustion Trial F. There was a sintered deposit 2 cm thick on the inside of the refractory collar (Fig. 2). There are few radiation and total heat flux measurements for this combustion trial due to the rate of flow of gases through the sample ports.

COMBUSTION TRIAL H

As indicated in Table A2-1, the fuel used for this combustion trial was the high-volatile coal code number 1. The particle size distribution of the pulverized fuel as burned is given in the following list:

Mesh size	Wt %
+100	0.0
-100 +140	4.0
-140 +200	12.0
-200 +325	66.0
-325 +400	11.0
-400	7.0

For this combustion trial the breakdown of the fines is given in Table A2-5.

Table A2-5 - Particle size distribution of the as-burned coal for combustion Trial H size range -400 mesh

CH.#	Size (μm)	Diff vol %	Cum vol %	Dif pop %	Cum pop %
1	4.00	0	100.0	0	100.0
2	5.04	.4	100.0	7.9	100.0
3	6.35	.9	99.6	10.8	92.1
4	8.00	2.4	98.7	15.6	81.3
5	10.08	5.0	96.3	16.7	65.7
6	12.70	10.1	91.3	16.9	49.0

Table A2-5 (Cont'd)

CH.#	Size (μm)	Diff vol %	Cum vol %	Dif pop %	Cum pop %
7	16.00	16.0	81.2	14.2	32.1
8	20.16	22.3	65.2	10.2	17.9
9	25.40	25.9	42.9	5.9	7.7
10	32.00	13.1	17.0	1.6	1.8
11	40.32	2.1	3.9	.1	.2
12	50.80	.4	1.8	0	.1
13	64.00	.3	1.4	0	.1
14	80.63	.9	1.1	0	.1
15	101.59	.1	.2	0	.1
16	128.00	.2	.1	0	.1

Up to this point in the combustion trials, it was thought that the gases exited the sample ports due to the eccentricity of the flow pattern inside the furnace; however, through experimentation it was found that the pressure inside the furnace was higher than expected. As a result, the furnace draft measurement location was changed to about 4.65 m from the burner. This allowed for a much better adjustment of the furnace pressure and a control on the rate of gases leaving the furnace via the sample ports. The flame was very good for this combustion trial; however, it tended to lean to the side opposite to the sample ports. The pipe between the pulverizer and the furnace was reduced to 6.35 cm to increase the velocity of the gases carrying the coal to the burner. A friable deposit was found on the quarl straight section and the refractory ring (Fig. 2) after the combustion trial. The radiometer and total heat flux measurement procedure was the same as that for combustion Trial G.

COMBUSTION TRIAL I

As indicated in Table A2-1, the fuel used for this combustion trial was the high-volatile coal code number 1. The particle size distribution of the pulverized fuel as burned is given in the following analysis:

Mesh size	Wt %
+100	0.0
-100 +140	2.0
-140 +200	11.0
-200 +325	69.0
-325 +400	10.0
-400	8.0

For this combustion trial the breakdown of the fines is given in Table A2-6.

Table A2-6 - Particle size distribution of the as-burned coal for combustion Trial I size range -400 mesh

CH.#	Size (μm)	Diff vol %	Cum vol %	Dif pop %	Cum pop %
1	4.00	.1	100.0	0	100.0
2	5.04	.5	99.9	9.8	100.0
3	6.35	1.1	99.4	11.9	90.2
4	8.00	2.7	98.3	16.4	78.3
5	10.08	5.1	95.6	15.8	61.9
6	12.70	9.7	90.5	15.7	46.1
7	16.00	15.9	80.8	13.5	30.4
8	20.16	22.9	64.9	9.8	16.9
9	25.40	24.9	42.0	5.4	7.1
10	32.00	14.6	17.1	1.7	1.7
11	40.32	1.5	2.5	.1	0
12	50.80	.2	1.0	0	0
13	64.00	.2	.8	0	0
14	80.63	.2	.6	0	0
15	101.59	.2	.4	0	0
16	128.00	.3	.2	0	0

The discussion giving the conditions for the combustion trial is the same as that for the combustion Trial H. For combustion Trials I to K, the radiometer and total heat flux measurements were permitted in the first metre of the furnace due to the change in the draft measurement location.

COMBUSTION TRIAL J

As indicated in Table A2-1, the fuel used for this combustion trial was the low-volatile coal code number 3. The particle size distribution of the pulverized fuel as burned is given in the following analysis:

Mesh size	Wt %
+100	1.0
-100 +140	9.0
-140 +200	16.0
-200 +325	63.0
-325 +400	6.0
-400	5.0

For this combustion trial the breakdown of the fines is shown in Table A2-7.

Table A2-7 - Particle size distribution of the as-burned coal for combustion Trial J size range -400 mesh

CH.#	Size (μm)	Diff vol %	Cum vol %	Dif pop %	Cum pop %
1	4.00	.3	100.0	0	100.0
2	5.04	1.0	99.7	14.2	100.0
3	6.35	2.1	98.7	16.8	85.8
4	8.00	4.3	96.6	18.8	69.0
5	10.08	7.3	92.3	15.9	50.2
6	12.70	11.4	85.0	13.2	34.3
7	16.00	16.4	73.6	9.9	21.1
8	20.16	22.6	57.2	6.9	11.2
9	25.40	22.7	34.6	3.5	4.3
10	32.00	9.5	11.9	.8	.8

Table A2-7

CH.#	Size (μm)	Diff vol %	Cum vol %	Dif pop %	Cum pop %
11	40.32	.6	2.4	0	0
12	50.80	.4	1.8	0	0
13	64.00	.4	1.4	0	0
14	80.63	.4	1.0	0	0
15	101.59	.4	.6	0	0
16	128.00	.5	.2	0	0

As with the other low-volatile combustion trials (F and G), the flame was not very well defined. As such, the flame length measurements given in Table A2-1 are rather subjective. As a result of the deposits from the two previous high-volatile combustion trials, the angle of the quarl may have changed. Looking down the flame from the exit of the furnace, all that was visible was an orange fog that filled the interior of the furnace.

COMBUSTION TRIAL K

As indicated in Table A2-1, the fuel used for this combustion trial was the low-volatile coal code number 3. The particle size distribution of the pulverized fuel as burned is given in the following analysis:

Mesh size	Wt %
+100	0.3
-100 +140	2.0
-140 +200	7.0
-200 +325	74.0
-325 +400	9.0
-400	7.0

For this combustion trial the breakdown of the fines is given in Table A2-8.

Table A2-8 - Particle size distribution of the as-burned coal for combustion Trial K size range -400 mesh

CH.#	Size (μm)	Diff vol %	Cum vol %	Dif pop %	Cum pop %
1	4.00	.3	100.0	0.0	100.0
2	5.04	1.1	99.7	14.6	100.0
3	6.35	2.5	98.6	17.2	85.4
4	8.00	5.0	96.1	19.6	68.2
5	10.08	8.1	91.1	15.9	48.6
6	12.70	12.9	83.0	13.6	32.7
7	16.00	17.0	70.1	9.3	19.1
8	20.16	22.4	53.1	6.2	9.8
9	25.40	21.7	30.7	3.0	3.6
10	32.00	6.5	9.0	.5	.6
11	40.32	.7	2.5	0	.1
12	50.80	.3	1.8	0	.1
13	64.00	.4	1.5	0	.1
14	80.63	.4	1.1	0	.1
15	101.59	.4	.7	0	.1
16	128.00	.5	.3	0	.1

From observations at the exit of the furnace, it was found that the flame was better defined than for the previous combustion trial. Combustion gases and some flame were observed to be flowing out of the sample ports. The furnace draft was maintained at the same level as for previous combustion trials (positive 0.75 to 1.3 mm water); however, the combustion gases flowed out of the sample ports at a rate higher than expected. It is thought that the asymmetry noted in the velocity profile experiments may be responsible for this. The draft in the furnace was therefore reduced for the radiometer and total heat flux measurements in order not to bias the measurements. After the combustion trial, it was noticed that there were friable deposits on the quarl and sintered deposits on the refractory ring.

APPENDIX 3

SOURCES OF ERROR

APPENDIX 3

SOURCES OF ERROR

This Appendix discusses the possible sources of errors for the combustion trials described in this report. It is not intended to be an extensive study but simply an attempt to give an insight into the dependability of the measurements tabulated in the report. It should be noted that all of the measurement devices were calibrated before the combustion trials. Furthermore, the radiometers and gas analysis equipment had the calibration verified throughout the test series.

The error in the velocity measurement is discussed in Reference 4 and is expected to be in the range of 5 to 8%. For a detailed discussion of the measurement technique and the errors involved, it is suggested to read Reference 4. In some of the velocity profile data tables there are data missing. This is because the angle calculated for the velocity vector is beyond the acceptance angle for the velocity probe head and, as such, is rejected. This is apparent for the velocity measurements at the quarl exit for the low air flowrate and at the tunnel ports two and three for a swirl setting of 1.0. In these cases, the complete traverses were rejected because of large-scale flow instabilities. No reliable measurement could be made for these flow conditions.

The total heat flux measurements, as measured by the heat flux probe of Figure 6, are suspected to be in error by an unknown constant value. The measurements are included in this report to indicate the trend of the convected and conducted heat transferred with respect to that radiated by the flame. The reason for this error is due to two factors. The first source of error results from the method by which the measurement is taken. The total heat flux probe is inserted through an 11.0 cm diam hole along the axis of the furnace (Fig. 1). Because the furnace is maintained at a slightly positive pressure, the gases are allowed to exit the furnace in the region of the sample port. Therefore, the boundary layer over the probe is expected to be thinner than that over the interior wall of the furnace. As a result, the heat transfer measured by the probe is somewhat higher than that transferred to the wall of the furnace. The other source of error in the total heat flux measurement results from the fact that the surface temperature of the probe is not the same as that of the interior wall of the furnace. For this reason, the radiative exchange between the flame and the probe face is not the same as that between the flame and the furnace interior wall. It is suspected that the probe surface temperature is higher than the wall interior surface temperature and, as a result, the net radiated flux to the probe is lower than that to the furnace walls. The net effect of these two competing sources of error is not known and therefore it is recommended that only the trend of the total heat flux measurement be used. For accurate total heat flux measurements, it is recommended that the results of the cooling circuits be used.

As stated in the literature (5,6), the measurement of the radiated heat flux using the 2 PI radiometer of Figure 5 can be accurate to within 5%. In the case where hot combustion gases blow directly on the probe face (as in the Trials C to G see "Notes on the Combustion Trials", Appendix 2), the error in the measured radiation is not expected to be appreciable. This is due to the water cooling and purging of the ellipsoidal cavity.

There are three sources of error for the measurement of species concentration. These are:

- non-isokinetic sampling
- sample quenching
- distortion of the temperature and velocity fields.

The distortion of the temperature and velocity fields results from the physical presence of the probe in the gas stream. The mixing processes are disturbed and as a result the chemical reactions may be changed in the region of the probe. In addition to this, the cooled probe will extract heat from the gases and therefore may influence the chemical reactions near the probe. The effect of these distortions is expected to be minor relative to the other two sources of error. This is based on the discussion of Tiné (7). Errors resulting from non-isokinetic sampling and sample quenching are not easily determined but are not expected to exceed 10 to 20% (7).

The errors involved in the measurement of the gas temperature have two sources:

- distortion of the velocity and temperature fields
- improper heat transfer to the thermocouple.

The effect of these sources has been evaluated by Braud (5,6) and has been found to be insignificant.

For the calculation of the heat transferred to the 28 cooling circuits, there are three measurements required for each of the circuits. The temperature at the entrance and exit to the cooling circuit is measured along with the flow-rate of the coolant. Using these measurements and the specific heat of the fluid, it is possible to calculate the heat extracted from the flame by each of the C-shaped circuits. The calibration of the thermocouples and flow measuring device, and the specific heat of the coolant, are known to within a fraction of a percentage. Therefore, the calculation of the heat transferred to the cooling circuits is believed to be within 1 to 2%. Each C circuit is insulated one from the other and, as a result, the errors due to axial heat exchange are expected to be insignificant.

APPENDIX 4

COMBUSTION MEASUREMENTS

APPENDIX 4

COMBUSTION MEASUREMENTS

This Appendix includes the raw data collected during the combustion trials with the four fuels used. These fuels consist of a number 2 fuel oil, one high-volatile coal and two low-volatile coals. The conditions for the combustion trials, the number code used to identify the fuels, and their analyses are given in Appendix 2. The letter code for the combustion trials is described in Table 3.

The experimental results are arranged in the same manner for each of the combustion trials. To interpret subtle differences between each of the combustion trials, it is suggested that the discussion for the combustion trials in question be read.

Table A4-1 - Combustion Trial A - Axial variation of radial heat transfer

Axial distance (m)	Radial heat $watt/cm^2$
1.24	3.930
1.39	4.339
1.54	3.753
1.68	3.288
1.84	3.038
1.99	2.820
2.14	2.747
2.29	2.437
2.44	2.215
2.59	2.098
2.74	1.805
2.89	1.706
3.04	1.469
3.19	1.516
3.35	1.523
3.49	1.370
3.65	1.352
3.80	1.228
3.94	1.195
4.09	1.106
4.25	1.052
4.40	0.969
4.55	0.973
4.71	0.878
4.86	0.903
5.00	0.836
5.16	0.958
5.30	0.893

Table A4-2 - Combustion Trial A - Total heat flux and radiation measurements

Axial distance (m)	Total heat flux $watt/cm^2$	Radiative heat flux $watt/cm^2$
.61	13.0	11.4
.91	10.0	8.3
1.24	5.3	3.6
1.39	5.3	3.5
2.14	4.0	2.0
2.29	4.0	1.8
3.35	2.8	1.4
5.16	2.2	0.8

Table A4-3 - Combustion Trial A - Gas profile (vol % dry or ppm); profile separation = 10 cm

Axial Pos'n 0.91 m

Species	*1	2	3	4	5	6	7	8	9
O_2	4.5	4.9	6.75	7.0	4.5	3.7	3.7	3.6	3.0
CO_2	11.7	11.3	10.1	9.9	10.9	12.4	12.3	12.4	12.8
CO (ppm)	13.0	26.0	104.2	208.3	156.2	104.2	26.04	26.04	39.1
NO_x (ppm)	99	94	94	94	96	104	102	99	96

Axial Pos'n 1.39 m

Species	*1	2	3	4	5	6	7	8	9
O_2	5.7	6.0	5.5	4.7	4.3	4.2	3.8	3.75	3.75
CO_2	11.0	10.8	11.0	11.7	11.9	12.1	12.2	12.3	12.3
CO (ppm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.0
NO_x (ppm)	101.6	104.2	106.8	104.2	104.2	101.6	109.4	99.0	99.0

Axial Pos'n 2.29 m

Species	*1	2	3	4	5	6	7	8	9
O_2	5.2	5.0	4.5	4.2	4.0	4.3	4.25	4.5	4.2
CO_2	11.5	11.6	12.1	12.3	12.4	12.1	12.1	11.9	11.8
CO (ppm)	52.08	156.2	312.5	833.3	677.0	520.8	364.6	286.4	52.08
NO_x (ppm)	104.2	104.2	99	109.4	114.6	114.6	114.6	109.4	104.2

* indicates for wall +2.5 cm

Table A4-4 - Combustion Trial A - Temperature profile (°C); profile separation = 10 cm

Axial position (m)	*1	2	3	4	5	6	7	8	9	10
0.61	1024	1140	1183	1215	1240	1151	1033	952	920	-
0.91	980	1089	1136	1162	1130	1029	909	870	815	-
1.24	729	873	986	1051	1067	1010	921	813	777	709
2.14	730	792	831	840	843	814	750	730	705	661
3.35	600	625	638	624	630	630	622	622	629	620
5.16	479	51[illegible]	521	521	517	527	534	533	533	523

* indicates far wall + 2.5 cm

Table A4-5 - Combustion Trial B - Axial variation of radial heat transfer

Axial distance (m)	Radial heat watt/cm^2
1.24	4.6110
1.39	5.7506
1.54	4.7302
1.68	3.9479
1.84	3.3959
1.99	3.0212
2.14	2.7987
2.29	2.4582
2.44	2.1589
2.59	2.0121
2.74	1.7160
2.89	1.5985
3.04	1.3725
3.19	1.3931
3.35	1.3753
3.49	1.2216
3.65	1.2109
3.80	1.0838
3.94	1.0545
4.09	0.9824
4.25	0.8995
4.40	0.8152
4.55	0.8104
4.71	0.7312
4.86	0.7322
5.00	0.6916
5.16	0.7892
5.30	0.7333

Table A4-6 - Combustion Trial B - Total heat flux and radiation measurements

Axial distance (m)	Total heat flux watt/cm^2	Radiative heat flux watt/cm^2
.61	13.5	12.70
.91	10.0	9.40
1.24	6.3	4.05
1.39	6.3	4.15
2.14	3.5	2.04
2.29	3.2	1.95
3.35	2.2	1.18
5.16	2.1	1.03

Table A4-7 - Combustion Trial B - Gas profile (vol % dry or ppm); profile separation = 10 cm

Axial Pos'n 0.91 m

Species	*1	2	3	4	5	6	7	8	9
O_2	4.0	2.75	2.25	3.4	5.1	6.3	7.0	7.8	9.2
CO_2	12.7	13.4	13.8	13.0	11.6	10.6	10.2	9.6	8.8
CO (ppm)	70	150	240	82	30	20	20	18	18
NO_x (ppm)	114.6	114.6	114.6	104.2	93.8	83.4	83.4	72.9	65.1

Axial Pos'n 1.39 m

Species	*1	2	3	4	5	6	7	8	9
O_2	4.2	5.0	6.25	6.3	6.9	7.75	8.25	8.75	8.6
CO_2	12.3	11.6	10.8	10.6	10.2	9.7	9.4	9.1	9.2
CO (ppm)	20	20	20	20	20	20	20	20	20
NO_x (ppm)	104.2	99	93.8	88.6	83.4	78.2	72.9	70.3	67.9

Axial Pos'n 2.29 m

Species	*1	2	3	4	5	6	7	8	9
O_2	4.9	5.25	6.0	6.3	6.75	6.75	6.8	6.9	7.0
CO_2	12.0	11.6	11.0	10.8	10.5	10.4	10.4	10.4	10.2
CO (ppm)	0	0	0	0	0	20	20	25	25
NO_x (ppm)	104.2	101.6	93.8	93.8	88.6	88.6	88.6	83.4	83.4

* indicates far wall + 2.5 cm

Table A4-8 - Combustion Trial B - Temperature profile; profile separation = 10 cm

Axial position (m)	*1	2	3	4	5	6	7	8	9	10
0.61	1179	1231	1254	1144	961	876	879	925	-	-
0.91	1120	1122	1050	942	842	805	816	867	-	-
1.24	948	1012	941	836	772	742	736	741	800	810
2.14	769	770	722	670	676	676	712	738	758	730
3.35	563	600	595	590	592	604	634	673	700	647
5.16	470	509	513	519	520	522	530	556	560	515

* indicates far wall + 2.5 cm

Table A4-9 - Combustion Trial C - Axial variation of radial heat transfer

Axial distance (m)	Radial heat watt/cm^2
1.24	3.4951
1.39	3.3701
1.54	3.2354
1.68	3.0455
1.84	2.8325
1.99	2.6590
2.14	2.5030
2.29	2.3701
2.44	2.1435
2.59	2.0430
2.74	1.8178
2.89	1.6898
3.04	1.6322
3.19	1.5353
3.35	1.5106
3.49	1.3719
3.65	1.3651
3.80	1.2379
3.94	1.2304
4.09	1.0213
4.25	1.0621
4.40	1.0304
4.55	0.9841
4.71	0.9046
4.86	0.9213
5.00	0.8436
5.16	0.9545
5.30	0.8607

Table A4-10 - Combustion Trial C - Total heat flux and radiation measurements

Axial distance (m)	Total heat flux watt/cm^2	Radiative heat flux watt/cm^2
.61	10.3	9.5
.91	8.6	8.0
1.24	6.2	6.0
1.39	5.7	4.6
2.14	4.8	3.0
2.29	4.7	3.5
3.35	3.6	2.5
5.16	2.3	1.5

Table A4-11 - Combustion Trial C - Gas profile (vol % dry or ppm); profile separation = 10 cm

Axial Pos'n 1.39 m

Species	*1	2	3	4	5	6	7	8	9
O_2	4.8	1.0	0.5	4.6	4.2	4.2	4.5	4.9	5.7
CO_2	15.0	17.6	18.0	14.9	15.2	15.4	15.0	14.7	13.8
CO (ppm)	130.2	5000	5000	177.07	156.2	156.2	156.2	26.0	13.0
NO_x (ppm)	660	400	260	700	730	710	690	670	640

Axial Pos'n 2.29 m

Species	*1	2	3	4	5	6	7	8	9
O_2	4.4	4.7	4.5	4.4	4.5	4.7	4.7	4.4	4.8
CO_2	14.8	14.8	15.0	14.9	14.9	14.8	14.6	14.8	14.9
CO (ppm)	25	25	75	25	25	25	25	25	25
NO_x (ppm)	770	740	750	750	730	730	730	730	730

Axial Pos'n 3.35 m

Species	*1	2	3	4	5	6	7	8	9
O_2	4.0	4.5	4.4	3.8	3.6	4.8	5.2	5.8	-
CO_2	15.2	14.6	14.6	15.0	15.8	14.6	14.2	13.9	-
CO (ppm)	1250	200	150	200	300	350	450	250	-
NO_x (ppm)	690	700	740	750	720	670	620	610	-

* indicates far wall + 2.5 cm

Table A4-12 - Combustion Trial C - Temperature profile; profile separation = 10 cm

Axial position (m)	*1	2	3	4	5	6	7	8	9	10
0.61	1041	1106	1175	1221	1259	1200	1090	997	-	-
0.91	1010	1083	1160	1174	1180	1100	1016	958	-	-
1.24	880	957	1010	1050	1057	1020	967	890	886	870
2.14	817	864	890	893	887	817	816	811	801	733
3.35	651	711	700	714	693	680	680	679	681	633
5.16	511	542	552	552	560	570	582	563	545	505

* indicates far wall + 2.5 cm

Table A4-13 - Combustion Trial D - Axial variation of radial heat transfer

Axial distance (m)	Radial heat watt/cm^2
1.24	4.1401
1.39	3.9387
1.54	3.6780
1.68	3.4470
1.84	3.1405
1.99	2.9023
2.14	2.7510
2.29	2.5265
2.44	2.2604
2.59	2.0682
2.74	1.7204
2.89	1.5828
3.04	1.4385
3.19	1.3503
3.35	1.3073
3.49	1.1316
3.65	1.0995
3.80	0.9777
3.94	0.9777
4.09	0.8707
4.25	0.8258
4.40	0.7819
4.55	0.7709
4.71	0.7075
4.86	0.7126
5.00	0.6708
5.16	0.7410
5.30	0.7069

Table A4-14 - Combustion Trial D - Total heat flux and radiation measurements

Axial distance (m)	Total heat flux watt/cm^2	Radiative heat flux watt/cm^2
.61	12.2	11.3
.91	10.8	9.2
1.24	7.2	6.8
1.39	7.6	7.0
2.14	5.2	3.8
2.29	4.6	3.7
3.35	2.9	1.6
5.16	2.2	1.0

Table A4-15 - Combustion Trial D - Gas profile (vol % dry or ppm);
profile separation = 10 cm

Axial Pos'n 1.39 m

Species	*1	2	3	4	5	6	7	8	9
O_2	4.5	4.8	4.9	4.9	4.7	4.8	4.6	4.8	4.9
CO_2	15.1	14.8	14.9	14.9	14.8	15.1	15.1	14.7	14.8
CO (ppm)	00	00	00	100	50	25	25	25	00
NO_x (ppm)	800	780	780	775	780	780	780	765	770

Axial Pos'n 0.91 m

Species	*1	2	3	4	5	6	7	8	9
O_2	4.8	4.8	4.8	5.0	4.6	4.6	5.0	4.7	5.1
CO_2	14.5	14.4	14.4	14.3	14.6	14.6	14.2	14.6	14.2
CO (ppm)	25	25	25	25	25	25	25	00	00
NO_x (ppm)	740	745	740	735	775	765	755	770	755

Axial Pos'n 2.29 m

Species	*1	2	3	4	5	6	7	8	9
O_2	4.8	4.9	4.8	4.6	4.7	4.7	4.7	4.9	5.3
CO_2	14.5	14.3	14.5	14.6	14.6	14.6	14.6	14.2	13.8
CO (ppm)	00	00	00	00	00	00	00	00	00
NO_x (ppm)	775	760	760	760	760	760	750	690	680

* indicates far wall + 2.5 cm

Table A4-16 - Combustion Trial D - Temperature profile; profile separation = 10 cm

Axial position (m)	*1	2	3	4	5	6	7	8	9	10
0.61	870	900	963	1062	1160	1200	1130	1080	-	-
0.91	821	871	980	1050	1092	1130	1142	1081	-	-
1.24	692	780	846	882	960	1012	1034	1043	1033	1025
2.14	731	744	800	836	890	900	912	920	878	833
3.35	600	622	640	670	667	630	679	677	652	617
5.16	500	522	510	494	495	510	504	507	502	491

* indicates far wall + 2.5 cm

Table A4-17 - Combustion Trial E - Axial variation of radial heat transfer

Axial distance (m)	Radial heat watt/cm^2	Axial distance (m)	Radial heat watt/cm^2
1.24	3.4901	3.35	1.6907
1.39	3.4318	3.49	1.4853
1.54	3.2315	3.65	1.4502
1.68	2.9938	3.80	1.3222
1.84	2.8397	3.94	1.3261
1.99	2.6600	4.09	1.2028
2.14	2.5500	4.25	1.1358
2.29	2.4351	4.40	1.0605
2.44	2.1802	4.55	1.0429
2.59	2.0736	4.71	0.9477
2.74	1.8892	4.86	0.9555
2.89	1.7466	5.00	0.9061
3.04	1.7367	5.16	1.0000
3.19	1.6756	5.30	0.9098

Table A4-18 - Combustion Trial E - Total heat flux and radiation measurements

Axial distance (m)	Total heat flux watt/cm^2	Radiative heat flux watt/cm^2
.61	10.0	8.4
.91	8.3	6.8
1.24	5.1	4.4
1.39	4.7	3.8
2.14	3.7	2.3
2.29	3.2	2.2
3.35	2.8	1.2
5.16	1.4	0.8

Table A4-19 - Combustion Trial E - Gas profile (vol % dry or ppm); profile separation = 10 cm

Axial Pos'n 1.39 m

Species	*1	2	3	4	5	6	7	8	9
O_2	3.8	4.1	4.5	4.7	4.4	4.8	5.2	6.3	5.6
CO_2	15.9	15.5	15.0	14.9	15.2	14.8	14.4	13.5	13.9
CO (ppm)	80.0	245	170	50	40	35	35	40	130
NO_x (ppm)	670	645	640	610	630	620	605	550	560

Axial Pos'n 2.29 m

Species	*1	2	3	4	5	6	7	8	9
O_2	4.2	4.5	4.8	4.4	4.3	4.7	4.8	4.8	5.6
CO_2	15.4	15.0	14.6	15.0	15.2	14.7	14.5	14.5	13.7
CO (ppm)	35	35	35	35	35	30	30	40	50
NO_x (ppm)	640	650	630	650	655	630	630	620	580

Axial Pos'n 3.35 m

Species	*1	2	3	4	5	6	7	8	9
O_2	4.7	4.4	4.6	5.2	5.4	5.8	5.3	11.4	12.7
CO_2	14.8	15.0	14.8	14.2	13.9	13.6	13.0	8.5	7.3
CO (ppm)	30	30	30	30	30	30	30	25	25
NO_x (ppm)	625	630	585	580	575	560	00	00	00

* indicates far wall + 2.5 cm

Table A4-20 - Combustion Trial E - Temperature profile; profile separation = 10 cm

Axial position (m)	*1	2	3	4	5	6	7	8	9	10
0.61	-	-	-	-	-	-	-	-	-	-
0.91	-	-	-	-	-	-	-	-	-	-
1.24	867	926	930	951	931	870	810	730	729	674
2.14	780	790	761	765	755	743	726	710	707	657
3.35	640	657	657	641	638	614	645	657	660	608
5.16	504	511	527	520	526	543	543	543	541	487

* indicates far wall + 2.5 cm

Table A4-21 - Combustion Trial F - Axial variation of radial heat transfer

Axial distance (m)	Radial heat watt/cm^2	Axial distance (m)	Radial heat watt/cm^2
1.16	5.7147	3.27	2.4861
1.31	4.7910	3.41	2.1682
1.46	4.9317	3.57	2.1022
1.60	5.0528	3.72	1.8581
1.76	4.9060	3.86	1.8504
1.91	4.6350	4.01	1.6374
2.06	4.5462	4.17	1.4837
2.21	4.1302	4.32	1.3756
2.36	3.6902	4.47	1.3045
2.51	3.3908	4.63	1.2054
2.66	3.1032	4.78	1.1929
2.81	2.9398	4.92	1.1253
2.96	2.9398	5.08	1.1483
3.11	2.5822	5.22	1.0813

Table A4-22 - Combustion Trial F - Total heat flux and radiation measurements

Axial distance (m)	Total heat flux watt/cm^2	Radiative heat flux watt/cm^2
.53	21.8	16.8
.83	20.6	14.0
1.16	14.4	10.0
1.31	14.0	9.5
2.06	8.2	5.4
2.21	8.0	4.2
3.27	3.8	2.0
5.08	1.4	1.2

Table A4-23 - Combustion Trial F - Gas profile (vol % dry or ppm);
profile separation = 10 cm

Axial Pos'n 1.31 m

Species	*1	2	3	4	5	6	7	8	9
O_2	6.2	7.5	7.7	7.5	8.2	8.4	8.4	6.8	6.6
CO_2	12.5	11.2	11.1	11.3	10.7	10.6	10.6	12.1	12.3
CO (ppm)	-	760	500	300	260	255	290	230	130
NO_x (ppm)	465	300	415	430	400	405	395	480	480

Axial Pos'n 2.21 m

Species	*1	2	3	4	5	6	7	8	9
O_2	7.6	6.4	6.3	6.5	6.9	7.0	6.9	6.7	6.6
CO_2	11.5	12.5	12.6	12.4	12.0	12.0	12.0	12.1	12.1
CO (ppm)	155	900	650	450	135	65	55	95	80
NO_x (ppm)	420	450	480	485	480	480	490	495	500

Axial Pos'n 3.27 m

Species	*1	2	3	4	5	6	7	8	9
O_2	7.1	7.3	7.2	7.2	7.1	7.3	7.7	7.5	7.4
CO_2	11.7	11.5	11.7	11.7	11.9	11.6	11.2	11.2	11.4
CO (ppm)	40	40	40	35	40	35	40	80	140
NO_x (ppm)	460	450	465	470	485	470	455	460	470

* indicates far wall + 2.5 cm

Table A4-24 - Combustion Trial F - Temperature profile; profile separation = 10 cm

Axial position (m)	*1	2	3	4	5	6	7	8	9	10
1.16	1012	1069	1096	1085	1075	1071	1102	1103	1083	980
2.06	863	916	923	921	909	908	912	910	897	860
3.27	629	666	691	694	697	690	691	696	705	660
5.08	438	468	476	496	507	508	520	527	539	539

* indicates far wall + 2.5 cm

Table A4-25 - Combustion Trial G - Axial variation of radial heat transfer

Axial distance (m)	Radial heat watt/cm^2	Axial distance (m)	Radial heat watt/cm^2
1.16	5.0670	3.27	2.0246
1.31	4.5292	3.41	1.7762
1.46	4.5843	3.57	1.6892
1.60	4.6643	3.72	1.5005
1.76	4.2630	3.86	1.6091
1.91	4.1023	4.01	1.3844
2.06	3.9553	4.17	1.1780
2.21	3.6763	4.32	1.0854
2.36	3.1271	4.47	1.0022
2.51	2.7402	4.63	0.9402
2.66	2.7487	4.78	0.8667
2.81	2.5216	4.92	0.8357
2.96	2.2451	5.08	0.8319
3.11	2.0957	5.22	0.7527

Table A4-26 - Combustion Trial G - Gas profile (vol % dry or ppm); profile separation = 10 cm

Axial Pos'n 1.31 m

Species	*1	2	3	4	5	6	7	8	9
O_2	4.2	6.7	7.3	7.5	9.2	9.8	9.4	8.9	8.9
CO_2	14.2	11.8	11.2	11.0	10.0	9.4	9.7	10.1	10.4
CO (ppm)	2100	1000	650	550	350	450	475	425	250
NO_x (ppm)	580	450	420	385	350	315	340	345	360

Axial Pos'n 3.27 m

Species	*1	2	3	4	5	6	7	8	9
O_2	7.3	7.2	7.0	7.1	7.5	7.3	7.8	7.7	7.7
CO_2	11.6	11.8	12.0	11.8	11.4	11.6	11.0	11.2	11.0
CO (ppm)	50	50	40	40	50	50	50	75	75
NO_x (ppm)	410	420	425	430	400	410	375	390	380

Axial Pos'n 2.21 m

Species	*1	2	3	4	5	6	7	8	9
O_2	7.4	6.9	6.7	7.4	7.3	7.1	6.8	6.5	6.5
CO_2	11.6	12.0	12.2	11.5	11.4	11.6	12.0	12.2	12.2
CO (ppm)	100	625	500	260	100	50	50	150	175
NO_x (ppm)	425	410	430	410	405	420	450	460	450

* indicates far wall + 2.5 cm

Table A4-27 - Combustion Trial G - Total heat flux and radiation measurements

Axial distance (m)	Total heat flux watt/cm^2	Radiative heat flux watt/cm^2
.53	-	-
.83	-	-
1.16	-	-
1.31	-	-
2.06	-	-
2.21	-	-
3.27	3.4	2.3
5.08	1.6	0.9

Table A4-28 - Combustion Trial G - Temperature profile; profile separation = 10 cm

Axial position (m)	*1	2	3	4	5	6	7	8	9	10
1.16	996	1104	1117	1095	1054	1042	1080	1091	1074	888
2.06	855	872	895	887	873	874	871	863	839	804
3.27	601	638	656	623	651	666	680	686	662	648
5.08	415	424	434	441	450	466	476	486	487	458

* indicates far wall + 2.5 cm

Table A4-29 - Combustion Trial H - Axial variation of radial heat transfer

Axial distance (m)	Radial heat watt/cm^2
1.18	4.6566
1.33	4.4403
1.48	4.0529
1.62	3.7978
1.78	3.4848
1.93	3.2336
2.08	3.1262
2.23	2.9098
2.38	2.5320
2.53	2.3476
2.68	2.1886
2.83	1.9741
2.98	1.8962
3.13	1.8008
3.29	1.7019
3.43	1.4600
3.59	1.4815
3.74	1.2890
3.88	1.4093
4.03	1.2323
4.19	1.1482
4.34	1.0745
4.49	1.0788
4.65	0.9961
4.80	1.0060
4.94	0.9578
5.10	1.0535
5.24	-

Table A4-30 - Combustion Trial H - Total heat flux and radiation measurements

Axial distance (m)	Total heat flux watt/cm^2	Radiative heat flux watt/cm^2
.55	-	-
.85	-	-
1.18	7.5	7.0
1.33	6.6	6.5
2.08	3.6	3.2
2.23	3.6	3.0
3.29	2.4	1.8
3..43	2.4	1.4
5.10	1.6	1.0

Table A4-31 - Combustion Trial H - Gas profile (vol % dry or ppm); profile separation = 10 cm

Axial Pos'n 1.33 m

Species	*1	2	3	4	5	6	7	8	9
O_2	6.9	6.2	6.5	6.4	7.1	7.3	7.6	7.8	7.6
CO_2	14.0	13.5	13.0	13.2	12.6	12.2	11.9	11.8	11.9
CO (ppm)	50	50	50	90	75	60	75	50	50
NO_x (ppm)	670	710	710	730	725	710	705	700	720

Axial Pos'n 2.23 m

Species	*1	2	3	4	5	6	7	8	9
O_2	7.4	7.4	7.3	7.4	7.8	7.6	7.8	7.7	7.8
CO_2	12.2	12.0	12.1	12.1	11.9	11.8	11.7	11.8	11.5
CO (ppm)	00	00	00	00	00	00	00	00	00
NO_x (ppm)	710	710	710	710	690	690	680	685	680

Axial Pos'n 3.29 m

Species	*1	2	3	4	5	6	7	8	9
O_2	7.8	7.3	7.7	7.6	7.4	7.6	7.8	7.8	7.9
CO_2	11.4	12.0	11.5	11.7	11.8	11.7	11.4	11.4	11.3
CO (ppm)	00	00	00	00	00	00	00	00	00
NO_x (ppm)	675	710	690	705	705	695	680	670	670

Axial Pos'n 5.10 m

Species	*1	2	3	4	5	6	7	8	9
O_2	7.3	7.1	7.6	7.8	7.6	7.7	7.7	7.7	7.5
CO_2	11.9	12.1	17.6	11.4	11.4	11.4	11.4	11.3	11.6
CO (ppm)	00	00	00	00	00	00	00	00	00
NO_x (ppm)	690	690	660	670	675	670	675	670	710

* indicates far wall + 2.5 cm

Table A4-32 - Combustion Trial H - Temperature profile; profile separation = 10 cm

Axial position (m)	*1	2	3	4	5	6	7	8	9	10
1.18	953	1059	1092	1108	1076	1031	1000	973	930	777
2.08	866	920	922	918	900	873	831	806	780	642
3.29	612	620	610	630	615	622	636	654	660	561
5.10	472	488	490	496	497	504	532	547	560	475

* indicates far wall + 2.5 cm

Table A4-33 - Combustion Trial I - Axial variation of radial heat transfer

Axial distance (m)	Radial heat watt/cm^2	Axial distance (m)	Radial heat watt/cm^2
1.18	4.9825	3.29	1.5766
1.33	5.1619	3.43	1.3636
1.48	4.4829	3.59	1.3638
1.62	4.0072	3.74	1.1934
1.78	3.4978	3.88	1.2780
1.93	3.0866	4.03	1.1157
2.08	2.9689	4.19	1.0326
2.23	2.7185	4.34	0.9549
2.38	2.4219	4.49	0.9593
2.53	2.2038	4.65	0.8771
2.68	2.0397	4.80	0.8866
2.83	1.8759	4.94	0.8302
2.98	1.7766	5.10	0.9036
3.13	1.6470	5.24	0.8563

Table A4-34 - Combustion Trial I - Total heat flux and radiation measurements

Axial distance (m)	Total heat flux watt/cm^2	Radiative heat flux watt/cm^2
.55	16.6	15.7
.85	14.2	11.9
1.18	10.0	7.0
1.33	9.6	6.2
2.08	4.5	3.1
2.23	4.0	2.9
3.29	2.5	1.7
5.10	2.0	0.8

Table A4-35 - Combustion Trial I - Gas profile (vol % dry or ppm); profile separation = 10 cm

Axial Pos'n 1.33 m

Species	*1	2	3	4	5	6	7	8	9
O_2	5.5	5.3	5.0	5.1	6.3	7.0	6.6	6.4	6.3
CO_2	14.2	14.4	14.6	14.6	13.4	12.5	14.2	13.2	13.4
CO (ppm)	25	25	50	75	50	50	25	25	25
NO_x (ppm)	760	775	790	800	730	690	710	710	730

Axial Pos'n 2.23 m

Species	*1	2	3	4	5	6	7	8	9
O_2	8.0	6.6	7.8	7.5	7.5	7.4	7.5	7.2	7.1
CO_2	11.6	13.0	11.8	12.2	12.2	12.2	12.2	12.5	12.6
CO (ppm)	00	10	00	00	00	00	00	00	00
NO_x (ppm)	680	730	670	680	690	685	690	710	715

Axial Pos'n 3.29 m

Species	*1	2	3	4	5	6	7	8	9
O_2	8.2	7.7	7.6	7.2	7.0	7.0	6.8	7.0	7.1
CO_2	11.4	12.0	12.0	12.4	12.6	12.4	12.6	12.5	12.4
CO (ppm)	00	00	00	00	00	00	00	00	00
NO_x (ppm)	610	635	655	690	700	700	700	700	695

Axial Pos'n 5.10 m

Species	*1	2	3	4	5	6	7	8	9
O_2	7.8	7.7	7.6	7.5	7.4	7.4	7.4	7.3	7.2
CO_2	11.6	11.8	11.9	12.0	12.1	12.1	12.1	12.0	12.2
CO (ppm)	00	00	00	00	00	00	00	00	00
NO_x (ppm)	630	630	640	650	660	670	670	670	690

* indicates far wall + 2.5 cm

Table A4-36 - Combustion Trial I - Temperature profile; profile separation = 10 cm

Axial position (m)	*1	2	3	4	5	6	7	8	9	10
1.18	850	980	1007	1030	1015	960	930	890	860	740
2.08	804	860	875	874	860	838	790	760	717	619
3.29	560	590	569	541	551	555	580	587	601	551
5.10	448	467	472	469	475	477	491	500	504	453

* indicates far wall + 2.5 cm

Table A4-37 - Combustion Trial J - Axial variation of radial heat transfer

Axial distance (m)	Radial heat watt/cm^2	Axial distance (m)	Radial heat watt/cm^2
1.18	5.7590	3.29	2.3558
1.33	4.8764	3.43	2.1043
1.48	4.7651	3.59	2.0311
1.62	4.7870	3.74	1.8758
1.78	4.5943	3.88	1.9198
1.93	4.3131	4.03	1.6853
2.08	4.1647	4.19	1.4676
2.23	3.8825	4.34	1.3734
2.38	3.3860	4.49	1.3019
2.53	3.1116	4.65	1.2119
2.68	2.8966	4.80	1.1243
2.83	2.7114	4.94	1.0877
2.98	2.4017	5.10	1.0796
3.13	2.5244	5.24	1.0080

Table A4-38 - Combustion Trial J - Total heat flux and radiation measurements

Axial distance (m)	Total heat flux watt/cm^2	Radiative heat flux watt/cm^2
.55	22	22.5
.85	19.3	19.6
1.18	12.3	12.2
1.33	12.6	11.0
2.08	7.4	5.6
2.23	7.2	5.2
3.29	3.5	2.6
3.43	3.1	2.3
5.10	2.1	1.2

Table A4-39 - Combustion Trial J - Gas profile (vol % dry or ppm); profile separation = 10 cm

Axial Pos'n 1.33 m

Species	*1	2	3	4	5	6	7	8	9
O_2	2.8	2.9	1.4	1.8	2.0	1.8	1.7	2.2	4.0
CO_2	16.4	16.2	17.4	17.0	16.8	17.1	17.1	16.7	15.0
CO (ppm)	1000	950	950	1200	900	950	1400	750	600
NO_x (ppm)	580	600	620	600	590	605	570	560	540

Axial Pos'n 2.23 m

Species	*1	2	3	4	5	6	7	8	9
O_2	2.1	2.2	2.1	1.6	2.2	3.0	3.2	3.3	3.2
CO_2	16.8	16.6	16.8	17.1	16.6	15.9	15.6	15.6	15.7
CO (ppm)	800	1000	900	750	700	700	650	650	600
NO_x (ppm)	680	640	640	620	600	610	600	600	570

Axial Pos'n 3.29 m

Species	*1	2	3	4	5	6	7	8	9
O_2	2.5	2.3	2.8	2.7	3.0	3.3	3.1	2.9	2.8
CO_2	16.2	16.4	16.0	16.1	15.8	15.4	15.6	16.0	15.8
CO (ppm)	150	150	175	175	200	200	200	200	275
NO_x (ppm)	640	640	630	640	630	610	610	630	620

Axial Pos'n 5.10 m

Species	*1	2	3	4	5	6	7	8	9
O_2	2.8	3.5	3.0	3.4	3.1	1.3	2.0	2.2	2.3
CO_2	15.8	15.1	15.6	15.2	15.4	17.1	16.4	16.4	16.2
CO (ppm)	150	150	150	150	150	150	100	100	100
NO_x (ppm)	640	610	620	620	620	640	660	670	660

* indicates far wall + 2.5 cm

Table A4-40 - Combustion Trial J - Temperature profile; profile separation = 10 cm

Axial position (m)	*1	2	3	4	5	6	7	8	9	10
1.18	1172	1255	1265	1230	1190	1135	1116	1075	1060	971
2.08	883	908	895	857	828	801	772	753	749	714
3.29	611	624	622	600	592	585	588	590	595	543
5.10	412	419	425	431	438	450	461	462	460	386

* indicates far wall + 2.5 cm

Table A4-41 - Combustion Trial K - Axial variation of radial heat transfer

Axial distance (m)	Radial heat watt/cm^2	Axial distance (m)	Radial heat watt/cm^2
1.18	5.6321	3.29	2.0934
1.33	5.1000	3.43	1.8463
1.48	4.9287	3.59	1.7737
1.62	4.8340	3.74	1.5984
1.78	4.5350	3.88	1.7141
1.93	4.1964	4.03	1.4967
2.08	3.9668	4.19	1.3706
2.23	3.6981	4.34	1.3129
2.38	3.1463	4.49	1.2511
2.53	2.8749	4.65	1.1267
2.68	2.6214	4.80	1.0531
2.83	2.4824	4.94	1.0344
2.98	2.2781	5.10	1.0707
3.13	2.2530	5.24	1.0218

Table A4-42 - Combustion Trial K - Total heat flux and radiation measurements

Axial distance (m)	Total heat flux watt/cm^2	Radiative heat flux watt/cm^2
.55	-	-
.85	27.7	27.2
1.18	22.1	18.4
1.33	17.5	14.8
2.08	8.4	6.6
2.23	7.2	6.4
3.29	3.4	2.5
5.10	2.2	1.0

Table A4-43 - Combustion Trial K - Gas profile (vol % dry or ppm); profile separation = 10 cm

Axial Pos'n 1.33 m

Species	*1	2	3	4	5	6	7	8	9
O_2	3.7	2.6	3.0	2.9	2.7	2.8	2.3	2.2	2.4
CO_2	15.6	16.7	16.2	16.2	16.4	16.3	16.7	16.7	16.6
CO (ppm)	500	600	600	450	600	400	550	500	400
NO_x (ppm)	770	800	770	780	780	760	770	800	830

Axial Pos'n 2.23 m

Species	*1	2	3	4	5	6	7	8	9
O_2	3.0	2.8	2.8	3.0	3.0	2.6	3.0	3.2	3.2
CO_2	15.9	16.0	16.1	15.9	15.9	16.2	15.9	15.6	15.8
CO (ppm)	100	300	250	250	300	300	400	500	750
NO_x (ppm)	765	780	790	775	790	790	780	780	780

Axial Pos'n 3.29 m

Species	*1	2	3	4	5	6	7	8	9
O_2	2.9	2.7	2.6	2.5	3.1	3.3	3.6	3.8	3.4
CO_2	15.9	16.0	16.1	16.2	15.6	15.3	15.1	14.9	15.4
CO (ppm)	50	50	50	50	50	50	60	100	125
NO_x (ppm)	800	800	820	820	830	820	810	790	830

Axial Pos'n 5.10 m

Species	*1	2	3	4	5	6	7	8	9
O_2	3.2	3.3	3.2	3.2	3.4	3.0	3.3	3.4	3.3
CO_2	15.6	15.4	15.6	15.6	15.4	15.6	15.3	15.2	15.3
CO (ppm)	50	50	50	50	50	50	50	50	50
NO_x (ppm)	830	810	820	840	830	840	830	830	830

* indicates far wall + 2.5 cm

Table A4-44 - Combustion Trial K - Temperature profile; profile separation = 10 cm

Axial position (m)	*1	2	3	4	5	6	7	8	9	10
1.18	980	1022	1046	1090	1122	1128	1132	1120	1060	976
2.08	729	760	763	790	807	821	827	829	815	712
3.29	617	615	606	605	608	614	633	638	636	541
5.10	465	476	478	482	485	488	484	474	466	371

* indicates far wall + 2.5 cm